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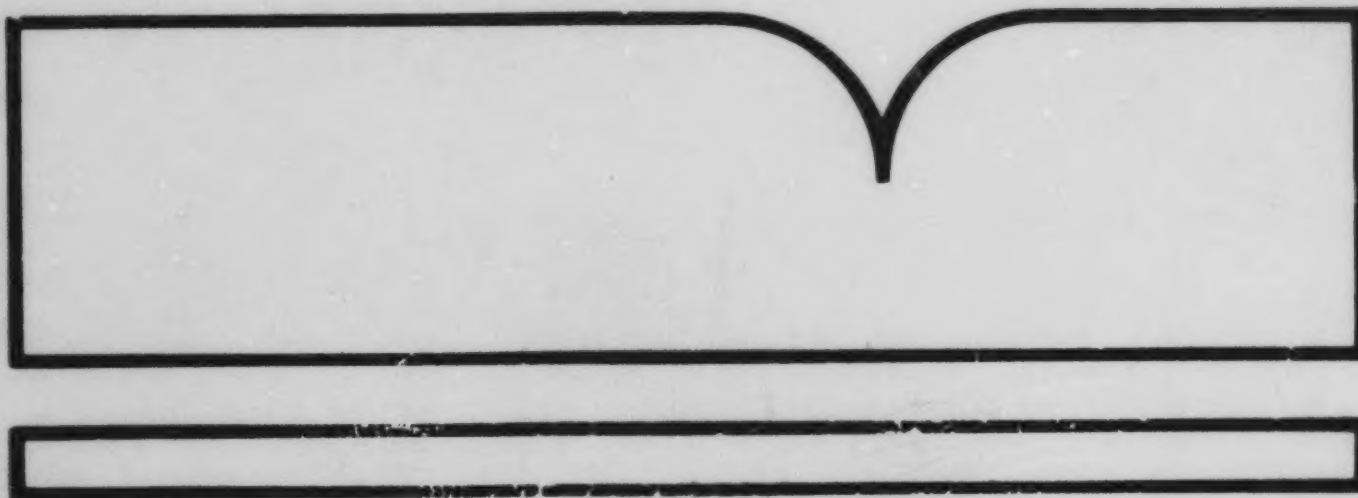
Evaluation of Low Emission Coal
Burner Technology on Industrial Boilers

Energy and Environmental Research Corp.
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EVALUATION OF LOW EMISSION COAL BURNER
TECHNOLOGY ON INDUSTRIAL BOILERS
Second Annual Report (1980)

by

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16. ABSTRACT The report summarizes the second year's effort under EPA Contract 68- 02-3127. The objective of the program is to conduct field evaluations of the distri- buted mixing burner (DMB) on two industrial size boilers. The DMB concept pro- vides for controlled mixing of coal with combustion air to minimize NOx emissions emissions, while maintaining an overall oxidizing environment in the furnace to minimize slagging and corrosion. Major accomplishments in 1980 included prepar- ation of a measurements protocol that specifies all measurements to be made during the program, baseline tests of the initial host boiler, and initial tests of a prototype DMB designed for the host boiler.		
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a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
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Coal	Corrosion	Stationary Sources
Combustion		Distributed Mixing Bur-
Burners		ners
Boilers		
Nitrogen Oxides		
Measurement		
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1.0

INTRODUCTION AND SUMMARY

For the last several years Energy and Environmental Research Corporation has been working with the EPA to develop a low NO_x pulverized coal burner. This "Distributed Mixing Burner" (DMB) provides for controlled mixing of the coal with combustion air to minimize NO_x emissions while maintaining an overall oxidizing environment in the furnace to minimize slagging, fouling and corrosion. DMBs have been tested at firing rates up to about 100×10^6 Btu/hr in single and four-burner arrays in two research furnaces. The tests covered wide ranges of burner adjustments and operating conditions. When fired in the research furnaces under optimum conditions, NO_x levels less than $0.15 \text{ lb}/10^6$ Btu were obtained. However, the DMB performance has not been evaluated in a commercially operated steam generator. The objective of this program (EPA Contract No. 68-02-3127) is to evaluate the DMB concept on two commercially operated industrial size boilers. The goal is to attain NO_x emission levels less than $0.2 \text{ lb}/10^6$ Btu without adverse effects on boiler operability and durability, thermal efficiency and the emissions of other pollutants. The field evaluations will involve: 1) translation of the development burner test data into practical prototype DMBs, 2) verification of the prototype burner performance through testing in a research furnace, 3) construction and installation of these burners in the field boilers and evaluation of performance under typical operating conditions, 4) documentation of the results, and 5) input to the parallel utility field evaluation (EPA Contract No. 68-02-3130).

To accomplish the program objectives, the efforts are organized into the following main tasks:

1. Program Definition
2. Prototype Construction and Testing
3. Boiler Characterization
4. Burner Installation
5. Performance Evaluation
6. Industry Coordination
7. Boiler Restoration
8. Data Analysis
9. Design Approach Documentation

Figure 1-1 shows how these tasks interact to achieve the program objectives. In Task 1, all of the basic elements of the program are planned including boiler selection, burner design and establishment of a measurements plan. Two host site boilers are selected and negotiations with the operators completed so that a firm schedule for the remaining aspects of the study can be established. The final burner designs are established once the boilers have been selected. Based on the final burner design established in Task 1, prototype burners including all controls are then constructed, installed in the Large Watertube Simulator Furnace (LWS) and evaluated using several coals as part of Task 2. In addition, during Task 2 the commercial burners used in the host site boilers are also evaluated in the LWS so that a one-to-one comparison of operating characteristics is determined and any potential problems are identified. At the conclusion of Task 2, the burners and burner systems are ready for fabrication and installation in the host site boilers.

While Task 1 is being accomplished, the Task 3 - Boiler Baseline Evaluations of the host units are initiated. This effort establishes the normal operating characteristics as well as the potential for reducing NO_x emissions by off design point operation. Following the baseline characterization, the low NO_x coal burners and all support systems are installed on each host boiler. The burner and burner systems then undergo checkout testing to ensure that they are able to perform in a manner similar to the original burners. Any necessary changes in the burner design required for operational flexibility are then accomplished, checked out in the prototype LWS unit and incorporated and verified in the host boiler before proceeding to Task 5 - Performance Evaluation.

At this point in the program, the low emission burner system is ready for extensive evaluation. The retrofit boiler is then run over a sufficient range of operating conditions consistent with the operational steam requirements to define the multi-burner optimization of emissions so that the operating point can be established. Once this is defined then long-term evaluations (18 months) are conducted with the boiler operating under a "normal duty cycle". At the conclusion of this task, the boiler/burner system is inspected and the condition of all systems documented. After conclusion of Task 5, Task 7 involves the restoration of the boiler to its original state.

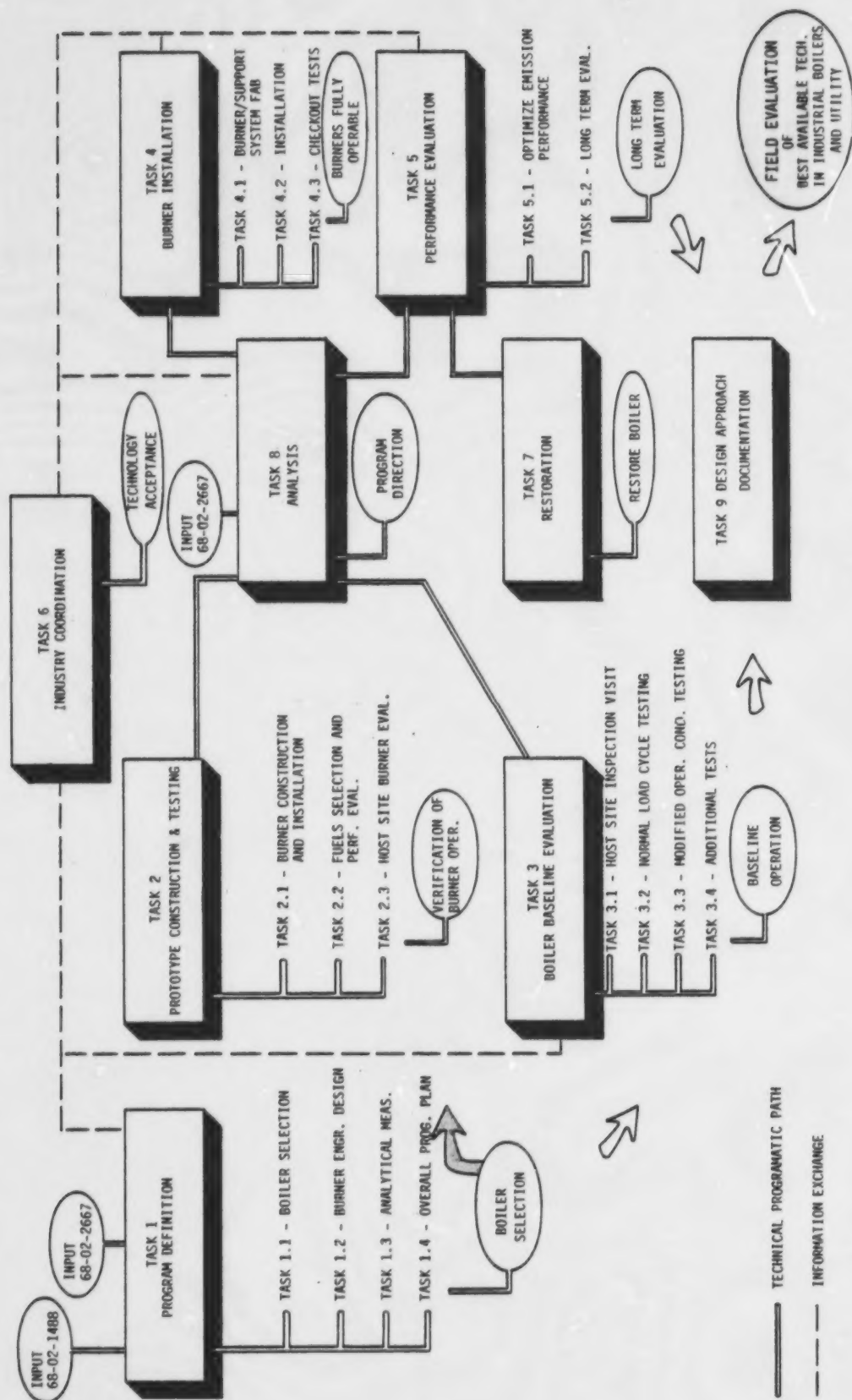


Figure 1-1. Overall Program Logic.

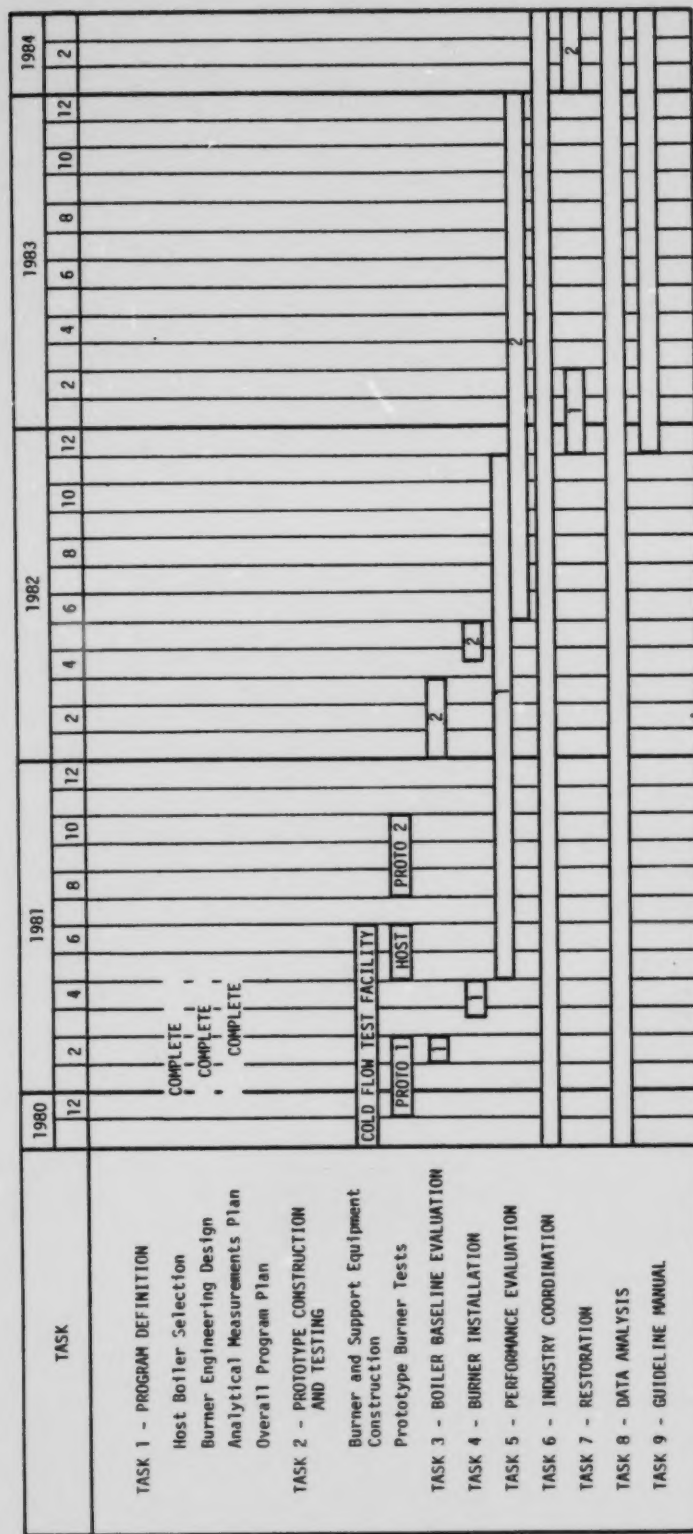
The remaining Tasks 6 and 8 are accomplished concurrent with all of the other tasks. Lastly, the Final Report, Task 9, involves integration of the over-all effort into a concise summary illustrating the application of the technology to a wide variety of coal-fired industrial boilers. F1-2

Figure 1-2 shows the program schedule presented in the previous annual report. The key element is the prototype burner tests in the LWS which were scheduled to begin in December 1979. Based on successful completion of these tests, the low NO_x burner installations at the field evaluation sites were scheduled for November 1980 and 1981.

When the prototype burner tests began, the LWS furnace walls were partially deteriorated. However, combustion calculations with oil-firing (where the fuel flow rate could be measured accurately) indicated that the air infiltration rate was small compared to the total combustion air flow rate. As testing progressed, the furnace walls deteriorated further, and testing was halted when the air infiltration rate increased to over 30 percent of the total combustion air flow rate.

The inability to complete the prototype burner tests made it impossible to install the burner at the initial field evaluation site as scheduled. The LWS has been rebuilt and prototype burner testing has resumed. Based on successful completion of these tests, the low NO_x burner installations at the field evaluation sites are now scheduled for Spring 1981 and 1982. T1-1

Table 1-1 summarizes the progress achieved to date on the various program tasks. The major accomplishments in 1980 include the initial prototype burner tests, preparation of the Measurements Protocol and the baseline tests at the initial field evaluation site. These items are discussed in Sections 2.0, 3.0, and 4.0 respectively. It should be noted that the prototype burner design discussed in this report is the initial "flexible" design based on the results of previous DMB development effort and Foster Wheeler burner components. In the course of testing the industrial prototype burner in the LWS (EPA Contract No. 68-02-3127), considerable changes in some design parameters were made including the incorporation of some proprietary Foster Wheeler components and parameter values. The results of this LWS testing and the changes in the burner designs will be documented in subsequent annual reports. The plans for the 1981 effort are summarized in Section 5.0.



1 - Related to Initial Demonstration
2 - Related to Second Demonstration

Figure 1-2. Revised Program Schedule.

Table 1-1. Program Status Summary

TASK	PROGRAM	FIRST FIELD EVALUATION	SECOND FIELD EVALUATION
Task 1 - Program Definition Host Boiler Selection Burner Engineering Design Analytical Measurements Plan Overall Program Plan	Boiler Inventory Evaluated Design Criteria Identified Measurements Protocol Completed	Selected Prototype DMB Designed Sampling System Constructed and Installed	Selected Sampling System Designed and Under Construction
Task 2 - Prototype Construction and Testing Burner and Support Equipment Construction Prototype Burner Tests Host Burner Tests	Cold Flow Test Facility Designed and Under Construction	Initial Testing Completed Initial Testing Completed Initial Testing Completed Scheduled for Spring 1981	Scheduled for 1981 Scheduled for Spring 1982
Task 3 - Boiler Baseline Evaluation Task 4 - Burner Installation Task 5 - Performance Evaluation Task 6 - Industry Coordination Task 7 - Restoration Task 8 - Data Analysis Task 9 - Guideline Manual	Two Panel Meetings Were Held	In Progress	

2.0

INITIAL PROTOTYPE BURNER TESTS

A prototype DMB has been designed, constructed and tested in the LWS. Figure 2-1 shows the organization of these tests into four phases. The first phase, flow characterization, includes the calibration of the prototype burner airflow measurement and control devices as well as the measurements of velocity profiles and swirl. The second phase, unstaged tests, includes firing the burner over the host site operating range to verify that the field burners can operate unstaged if a problem with the tertiary air system develops at the field evaluation site. The third phase, staged tests, involves testing the burner at its staged design point and optimizing the burner parameters for these test conditions. The final phase, Performance Optimization/Verification, includes the determination of burner operating conditions which result in an optimum balance of stability, efficiency and emissions over the host boiler operating range. It also includes verification that all burner systems (such as the ignitor/scanner system) and all burner performance aspects (such as the burner pressure drop) are compatible with the field boiler characteristics.

The prototype burner tests were initiated in December 1979. Shortly after testing began, the LWS furnace walls deteriorated and testing was halted. These initial tests utilized the baseline Utah coal and were primarily directed toward evaluation of burner performance unstaged (without tertiary air). Staged tests were also conducted but no attempt was made to optimize burner performance. However, the test results suggest that the field operable burner (which will be based on the prototype burner design) will be capable of approaching or meeting the program goal of $0.2 \text{ lb NO}_x/10^6 \text{ Btu}$.

The LWS has now been rebuilt. Unlike the old LWS which was cooled on all surfaces, the new LWS is partially lined with refractory. This produces a thermal environment which is comparable to the field boilers. The prototype burner has been retested in the new LWS under both unstaged and staged operating conditions. The NO_x emissions from these tests are nearly identical to the results obtained in the old LWS. This suggests that the NO_x emissions from the DMB are insensitive to furnace thermal environment at least over the range investigated. Thus the NO_x emissions from the DMBs operated in the field boilers are expected to be in the same range as the test results in the LWS.

The remainder of this section discusses the results of these tests and the implications for the field operable burner design. The following subsection

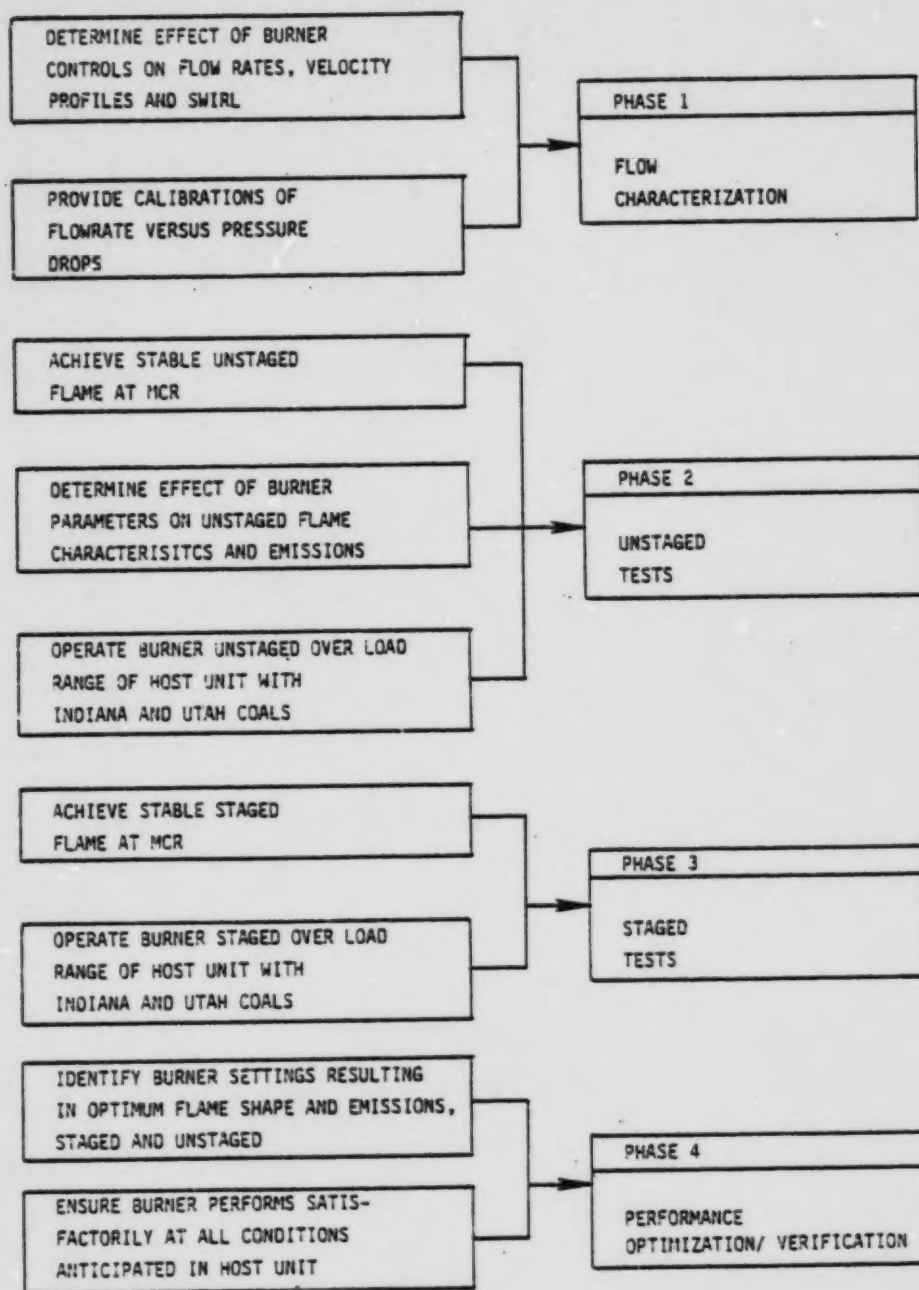


Figure 2-1. Prototype Burner Test Organization.

reviews the prototype burner design and subsection 2.2 discusses the Phase 1 Flow Characterization tests. The coal-fired tests in the old and new LWS are discussed in subsection 2.3. Predictions of the DMB performance in the field boilers based on these test results are presented in Section 2.4.

2.1 Prototype Burner Design

The prototype burner was designed by integrating the DMB design criteria and the host boiler characteristics into a commercial burner design. The development of the DMB design criteria was discussed in the previous annual report. Table 2-1 lists the final criteria. In many cases, the data from the development DMB tests were not sufficient to clearly identify optimum parameter values. Thus these criteria are nominal and are being used as the starting point for prototype burner testing and final optimization. The prototype burner has been designed to be flexible, that is to permit many of these parameters to be varied during testing.

The boiler selected for the initial field evaluation is Pearl Station which is owned and operated by Western Illinois Power Cooperative (WIPCO). Table 2-2 lists the characteristics of this unit which impact prototype burner design. The coal currently supplied to this unit is an Indiana bituminous coal with the characteristics listed in Table 2-3.

The Pearl Station characteristics are compatible with the DMB design criteria listed in Table 2-1 with the following exceptions:

- Windbox Depth and Burner Exit Length. The windbox depth is designed for the currently installed pre-NSPS Intervane burners which have a single register and a short exit. However, it is too short to accommodate the dual registers and exit length specified in the DMB design criteria. The maximum exit length which can be used corresponds to about 40 percent of the prototype DMB throat diameter, whereas the design criteria specify 100 percent. Burner exit geometry affects flame stability and the effects of this short exit length were evaluated in the prototype tests.
- Burner Spacing and Tertiary Port Locations. The burner spacing is too close for the tertiary ports to be located as specified in the design criteria. In addition, windbox and furnace structural considerations limit the potential tertiary port locations. Figure 2-2

Table 2-1. DMB Nominal Design Criteria

Burner System	Parameter	Nominal Design Point
Fuel	Swirl	45° Vanes
	Axial Velocity	22.9 m/sec (75 ft/sec)
Secondary Air	Stoichiometry	50-70% T.A.
	Swirl	Variable
	Axial Velocity	18.3 m/sec (60 ft/sec)
Tertiary Air	Number/Shape	4/Round
	Radius/Throat Diameter*	2.2
	Velocity	15.2 m/sec (50 ft/sec)
Exit	Half Angle	25°
	Length/Diameter**	1.0
	Setback	0

*Distance of port from burner centerline/burner throat diameter

Table 2-2. Initial Field Evaluation Site Characteristics

<u>PARAMETER</u>	<u>VALUE</u>
<u>Boiler</u>	
Configuration	Single Wall-Fired
Capacity MCR*	98×10^3 Kg/hr (215×10^3 lb/hr)
Peak	111×10^3 Kg/hr (245×10^3 lb/hr)
<u>Burners</u>	
Type	Foster Wheeler Intervane
Array	2 x 2
Capacity MCR	20 Thermal MW (69×10^6 Btu/hr)
Throat Diameter	61 cm (24 in.)
Spacing Horizontal	182 cm (71.5 in.)
Vertical	198 cm (78.0 in.)
<u>Furnace</u>	
Construction	Membrane Wall
Depth	6.28 m (20.6 ft.)
Width	5.01 m (16.4 ft.)
BZLR	492 Thermal kW/m ² (156×10^3 Btu/hr-ft ²)
<u>Fuel</u>	
Coal Type	Indiana Bituminous
Pulverizers Type	Foster Wheeler MB
Number	2
<u>Air Supply</u>	
Air Heater Type	Regenerative
Secondary Air Temperature	265°C (510°F)
Draft	Pressurized
Windbox Depth	132 cm (52 in.)
Burner Pressure Drop (Nominal)	8.9 cm H ₂ O (3.5 in. H ₂ O)

*MCR = Maximum Continuous Rating

Table 2-3. Initial Industrial Boiler Field Evaluation Site Coal Characteristics

	<u>As Received</u>	<u>Dry Basis</u>
<u>Proximate Analysis</u>		
% Moisture	13.03	
% Ash	10.14	11.66
% Volatile	36.08	41.49
% Fixed Carbon	<u>40.75</u>	<u>46.85</u>
	100.00	100.00
Heating Value Btu/LB	<u>11,700</u>	<u>12,600</u>
<u>Ultimate Analysis</u>		
Moisture	13.03	
Carbon	61.30	70.48
Hydrogen	4.36	5.01
Nitrogen	1.30	1.49
Chlorine	0.03	0.04
Sulfur	2.87	3.30
Ash	10.14	11.66
Oxygen (diff)	<u>6.97</u>	<u>8.02</u>
	100.00	100.00

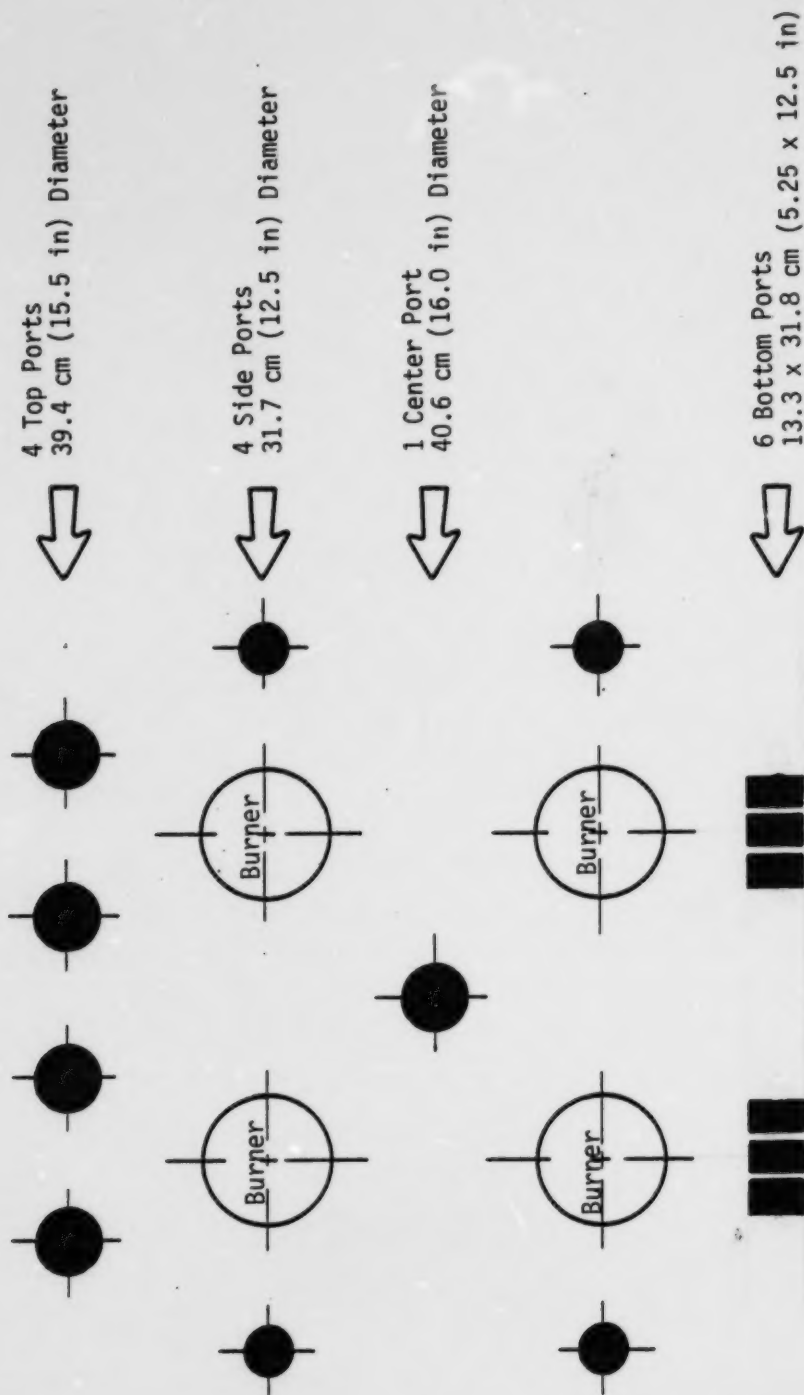


Figure 2-2. Tertiary Port Configuration of Initial Field Evaluation Boiler.

shows the tertiary port locations selected for the WIPCO unit. Although this configuration deviates from the design criteria, the tertiary air is well distributed around and between the burners and the velocity matches the design criteria. It should be noted that installation of the tertiary air ports results in removal of a buckstay and elimination of most of the firing wall support tubes. Consequently, an under hopper support must be installed. This technique is questionable for larger utility boilers and an alternate approach would have to be developed for this equipment.

Figure 2-3 is a cross-sectional view of the prototype burner showing its design details. The following Foster Wheeler commercial burner components have been incorporated into the design:

- Annular Coal Nozzle
- Telescoping Coal Nozzle for Primary Velocity Control
- Registers for Swirl Control and Flow Shutoff
- Air Hoods for Secondary Flow Rate Control and Measurement
- Commercial Flame Scanning and Ignition System

The coal and primary air enter the annular coal nozzle through a tangential inlet to provide swirl. The coal nozzle is a tapered annulus. The exit end of the coal nozzle is formed from two concentric cones. The inner cone can be moved axially to vary the exit area, and hence, the primary velocity. The outer portion of the coal nozzle is constructed of removable sections so that the overall length of the coal nozzle may be changed to vary the nozzle set-back within the burner throat. There are two concentric secondary air passages supplied from a common windbox. Each is equipped with an adjustable register for swirl control, an axially movable sleeve for flow control and a perforated plate (air hood) for flow rate measurement. Pressure taps on both sides of each perforated plate allow the pressure drop to be measured and correlated with sleeve position and flow rate.

The portion of the burner inside the coal nozzle is termed the core, and is supplied with a small amount of cooling air from the windbox. A retractable

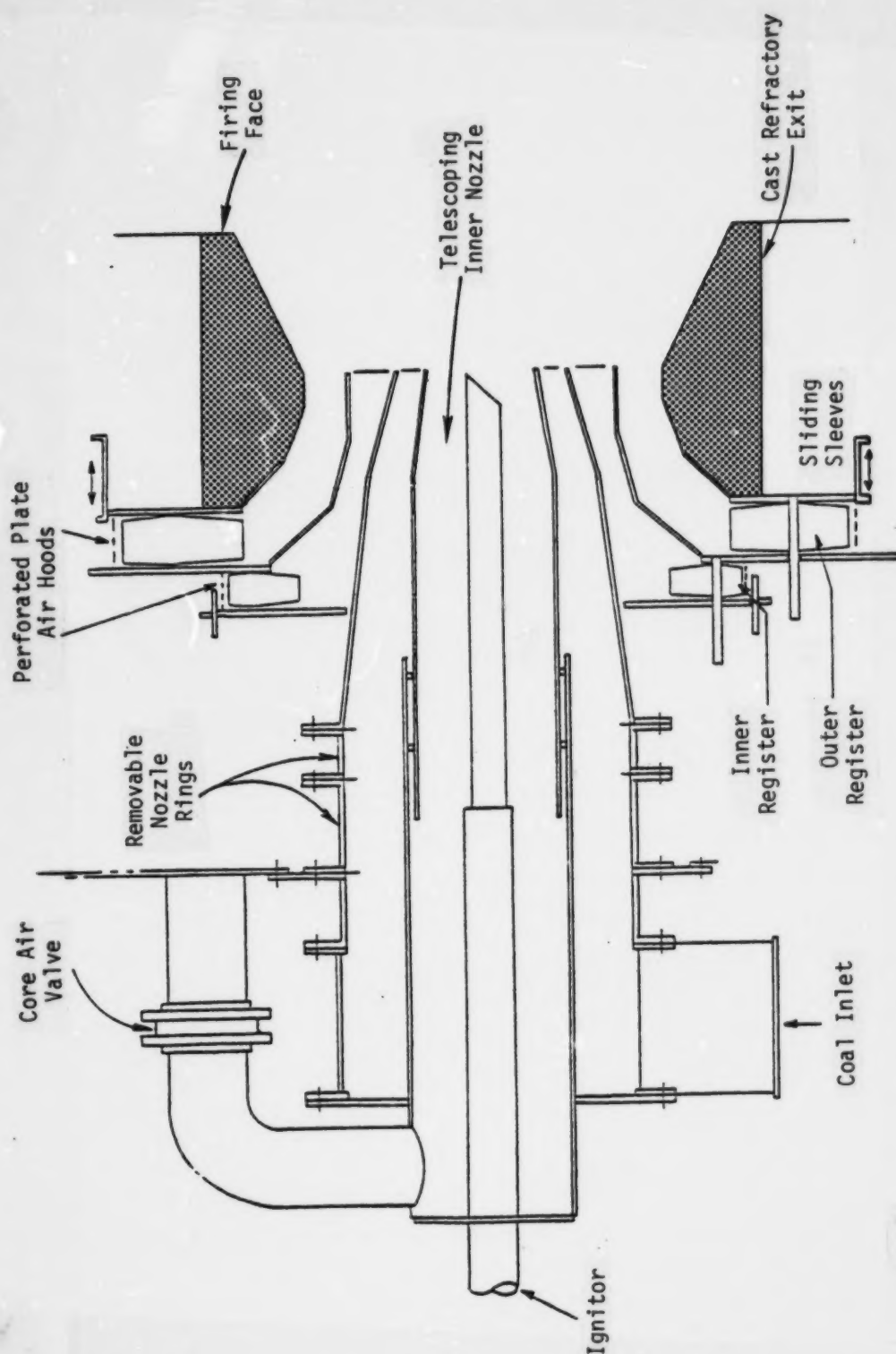


Figure 2-3. Prototype DMB Based on Foster Wheeler Design
(Tertiary Ports Not Shown).

ignition system, including spark ignition, a 2.9 thermal MW (10×10^6 Btu/hr) oil gun and an ignition flame scanner are located in the core on the burner centerline. The main flame scanner views the flame through the inner secondary air passage.

Tertiary (staging) air is supplied from the windbox through outboard tertiary air ports. During testing in the research facility the airflow rate through each port was controlled and measured by the assembly shown in Figure 2-4. The hemispherical poppet pivots to vary the open area, and thus, control the flow rate. The pressure drop across the perforated plate air hood provides an indication of flow rate. Alternate tertiary air port control system designs will also be evaluated during the prototype burner tests.

In summary, the prototype burner has been designed with "flexible" parameters to permit the flow rates, velocities and swirl in the burner passages to be varied to optimize burner performance. The dimensions and ranges of adjustment are listed in Table 2-4. All of the dimensions listed match the prototype design point except the exit length and tertiary port locations as previously discussed. The effects of these deviations from the design criteria are being evaluated as part of the prototype tests in the LWS.

2.2 Flow Characterizations

In the field evaluations, the low NO_x burners will be supplied with combustion air from a common windbox. To allow control and measurement of the airflow rates in each burner passage, the burners will be equipped with integral dampers and/or controls, as well as flowmeters. The objective of the Phase 1 Flow Characterization was to evaluate these devices on the prototype burner. The functional design of these devices and calibration methods are discussed in the following two sections. The evaluation of the devices on each burner passage are then presented. Lastly, the coordinated operation of these devices to control airflows in a common windbox is summarized.

2.2.1 Burner Internal Flow Measurements and Control Systems

The prototype burner is supplied with combustion air from two sources. The coal nozzle is supplied with air (and coal) from the pulverizer. The primary air flow rate is measured and controlled as part of the pulverizer system. The other burner passages are supplied with air from a common windbox. Figure 2-5 shows

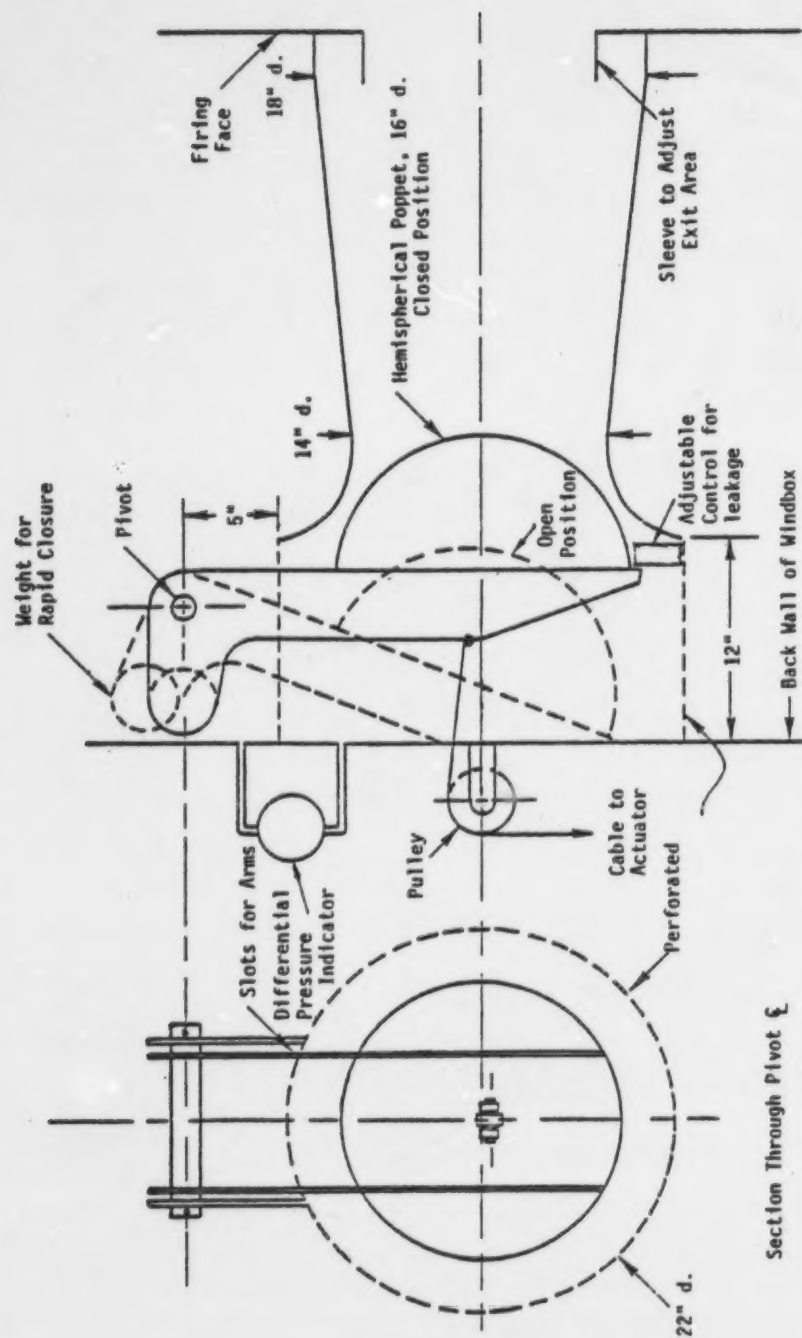


Figure 2-4. Tertiary Port Control Valve.

Table 2-4. Industrial Prototype Burner Dimensions and Adjustments

Design Variable	Nominal* Value	Adjustment	
		Range	Method
<u>Fuel Injector</u>			
Core Diameter (in.)	9.75		
Core Area (in. ²)	74.7		
Nozzle Diameter (in.)	14.5		
Annulus Thickness (in.)	2.375	1.7-3.3	} Telescoping Nozzle
Primary Area (in. ²)	90.5	68-136	
Setback (in.)	0	-2-+12	Remove/Replace Nozzle Rings
<u>Inner Secondary Channel</u>			
Outer Diameter (in.)	20.75	Variable	} Replace Secondary Divider
Annulus Thickness (in.)	3.125	Variable	
Area (in. ²)	173.0	Variable	
Setback (in.)	0	Variable	
<u>Outer Secondary Channel</u>			
Outer Diameter (in.)	30.25	Variable	} Recast Exit
Annulus Thickness (in.)	4.75	Variable	
Area (in.)	380.5	Variable	
Setback (in.)	0	Variable	
<u>Tertiary Ducts</u>			
Distance from Burner C _L (in.)	53	Variable	} Modify Windbox
Spacing Around Burner (deg)	90	Variable	
Number of Ports	4		
Injector Angle (deg.)	0		
Axial Position (in.)	0		
Diameter (in.)	13.25	Variable	} Sleeve
Total (in. ²)	553	Variable	
<u>Throat and Exit</u>			
Throat Diameter (in.)	30.25	Variable	} Recast Exit
Throat Area	718.7	Variable	
Half Angle of Exit (deg.)	25	Variable	
Length of Exit (in.)	12	Variable	
Length/Diameter	0.40	Variable	

* 1.0 in. = 2.54 cm
1.0 in.² = 6.45 cm²

the flow control and measurement devices which allow the distribution of air among the burner passages to be adjusted and monitored. The central burner passage (core) is connected to the windbox with a six-inch pipe equipped with a butterfly valve for flow control. The core airflow rate can be monitored by measuring the pressure drop across the valve. The relationship between airflow rate and pressure drop depends on the specific pressure tap locations, as well as valve position. Calibration is required.

The airflow measurement and control devices on each secondary passage include a sliding sleeve, a perforated plate (air hood) and a register. The primary function of the sliding sleeve is to vary the effective open area of the air hood and thus, vary the airflow rate. The primary function of the register is to provide swirl. However, the register is a flow restriction and affects the airflow rate as well. When the burner is removed from service, the register is closed to shut-off the airflow. The primary function of the air hood is to provide a pressure drop which can be used to monitor airflow rate. The relationship between pressure drop and airflow rate depends on sleeve position and, to a lesser extent, upon register position.

Each tertiary port is equipped with a perforated plate and a poppet valve. The components are arranged so that the perforated plate open area is constant, independent of poppet valve position. Thus, the pressure drop across the perforated plate can be used as a direct indication of flowrate and only a single calibration is required.

2.2.2 Calibration Methods and Procedures

The relationship between the airflow rate and the pressure drop across the measurement elements in the prototype burner can be expressed in the following form:

$$Q = K_1 \left(\frac{\Delta P_i}{T} \right)^{1/2}$$

where:

- Q = mass flow rate of air through the burner passage (SCFM)
- ΔP_i = pressure drop across the flow measurement device (in. H₂O)
- T = absolute air temperature (°R)

K_1 = a calibration constant which may depend on Reynolds Number, windbox pressure, the adjustments of adjacent flow control devices and effective open area of the flow measurement device.

For the high Reynolds Number flow conditions at which the measurement devices typically operate, Reynolds Number effects are usually small and can be neglected. Windbox pressure is usually only a few inches of H_2O greater than ambient and thus, changes in windbox pressure encountered in normal operation are small compared to the absolute pressure and have a negligible effect on calibration. Adjacent flow control devices, such as the registers may influence the calibration by altering the airflow in the vicinity of the pressure taps. This effect must be empirically evaluated. The relationship between K_1 and open area is approximately linear and must be calibrated.

The relationship between the airflow rate through a burner passage and windbox-to-furnace pressure differential may be expressed in a similar manner:

$$Q = K_2 \left(\frac{\Delta P_{wb}}{T} \right)^{1/2} \quad (2)$$

where the new symbols are defined as follows:

ΔP_{wb} = windbox-to-furnace pressure differential (in. H_2O)

K_2 = a calibration constant which depends on Reynolds Number and the adjustment of the airflow control devices.

It should be noted that the presence of a flame in the furnace may alter the effective ΔP_{wb} for some or all of the burner passages. Thus, cold flow calibrations may be slightly different than the actual fired performance.

The relationships between Q and ΔP_i or ΔP_{wb} were evaluated by physically blocking all burner passages which were not in use and measuring the airflow rate into the windbox with a calibrated venturi flowmeter. For selected tests, the airflow rates exiting the burner passages were measured by pitot tube traverses to ensure that leakage through the other burner passages could be neglected. Pressure drops were measured with manometers.

The effects of register position on swirl in the outer secondary air passage were measured with a five-hole probe. The magnitude and direction indicated by the probe were calibrated in a straight duct where the flow direction was known and the velocity was determined with a pitot tube.

2.2.3 Burner Flow Measurement System Calibrations

Core

The butterfly valve, which is used as the flow measurement element for the core, is the major restriction between the windbox and furnace. As expected, ΔP_i and ΔP_{wb} were found to be approximately equal for all test conditions. Figure 2-6 shows the relationship between the flowrate, pressure drop and temperature for several butterfly valve positions. Equations 1 and 2 are expressed by straight lines on the coordinates of Figure 2-6. These results show that the core air valve is an effective airflow rate control. Adjusting the valve from fully closed to fully open (at constant $\Delta P_i/T$) varies the airflow rate by a factor of 3.4. Least squares fits through the calibration data give the relationships shown in Table 2-5. The calibration constants for these relationships are shown as a function of the valve position in Figure 2-7. The relationship is approximately linear from full open to 60 degrees from full open. Table 2-5 also shows the final correlation which is valid over the linear range. The standard deviation for this correlation is 27 percent.

Outer Secondary

The air control systems for the secondaries each have three flow restrictions: sleeve, air hood and register. The pressure drop across the sleeve and air hood is used to monitor flow rate. This pressure drop is always less than the total windbox pressure drop due to the pressure drop across the register. Figure 2-8 shows the relationship between flow rate, pressure drop across the outer secondary sleeve and air hood, and temperature for several sleeve positions. The change in airflow rate as sleeve position is adjusted is approximately linear from zero to 75 percent open. However, opening the sleeve to 100 percent results in a smaller increase in airflow rate. This is due to the clearance between the sleeve and air hood. When the sleeve is nearly fully open, the flow restriction through the clearance is comparable to the flow restriction through the portion of the air hood covered by the sleeve. The clearance also affects the calibration when the sleeve is fully closed. In this case, all of the airflow passes through the clearance. Thus, the calibration of this device is sensitive to the clearance and the clearance should be closely controlled on the field operable burners.

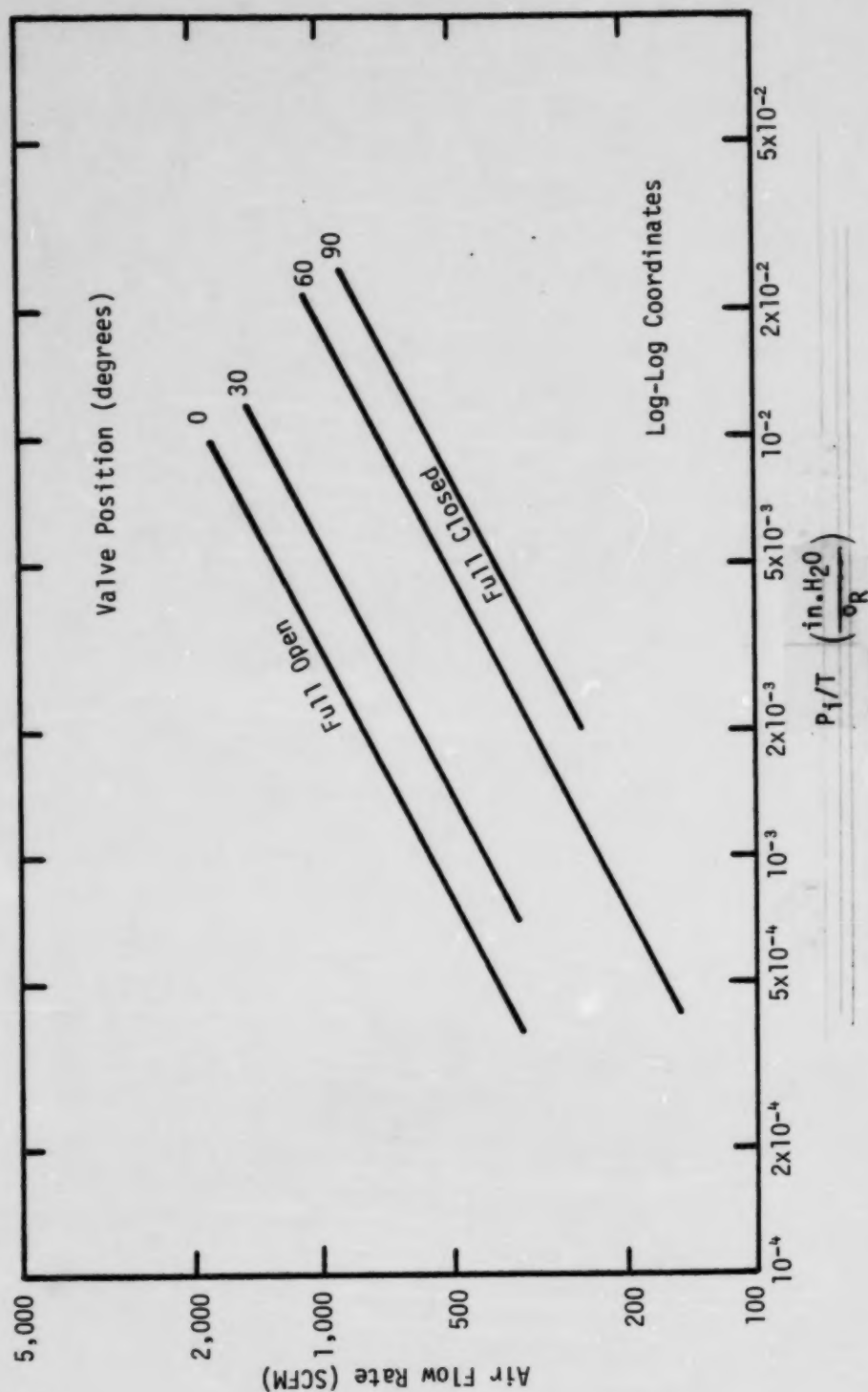


Figure 2-6. Core Air Valve Calibrations.

Table 2-5. Airflow Rate Correlations - Core

Core Valve Position	EQUATION	DEVIATION
0 Degrees	$Q = 18284 (\Delta P/T)^{1/2}$	$\pm 9.0\%$
30 Degrees	$Q = 13400 (\Delta P/T)^{1/2}$	$\pm 12.7\%$
60 Degrees	$Q = 7357 (\Delta P/T)^{1/2}$	$\pm 26.7\%$
90 Degrees	$Q = 5647 (\Delta P/T)^{1/2}$	$\pm 18.4\%$
	COMBINED RESULTS	
0 - 60 Degrees	$Q = (18475 - 182 P_V) (\Delta P/T)^{1/2}$	$\pm 27\%$

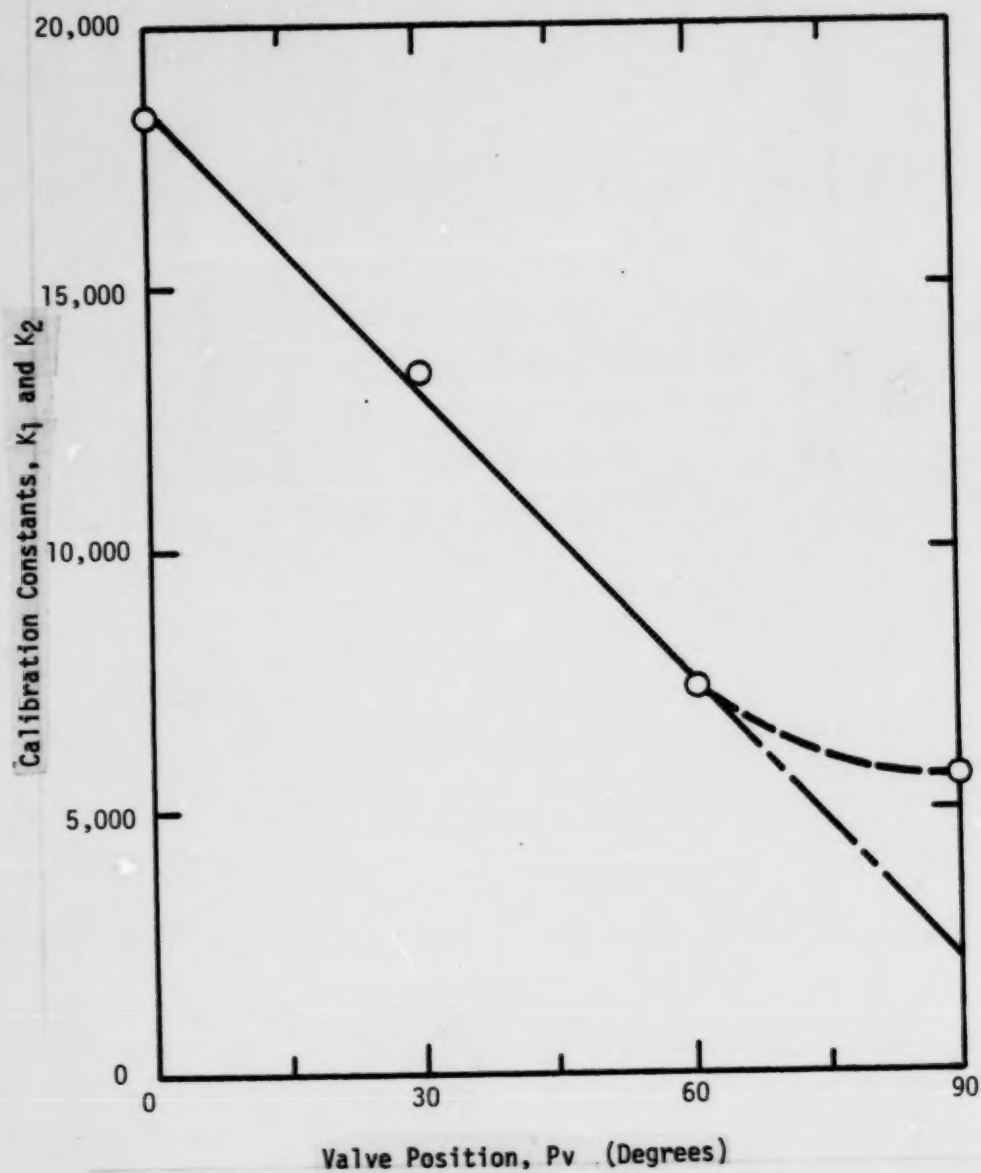


Figure 2-7. Calibration Constants For Core Air Valve.

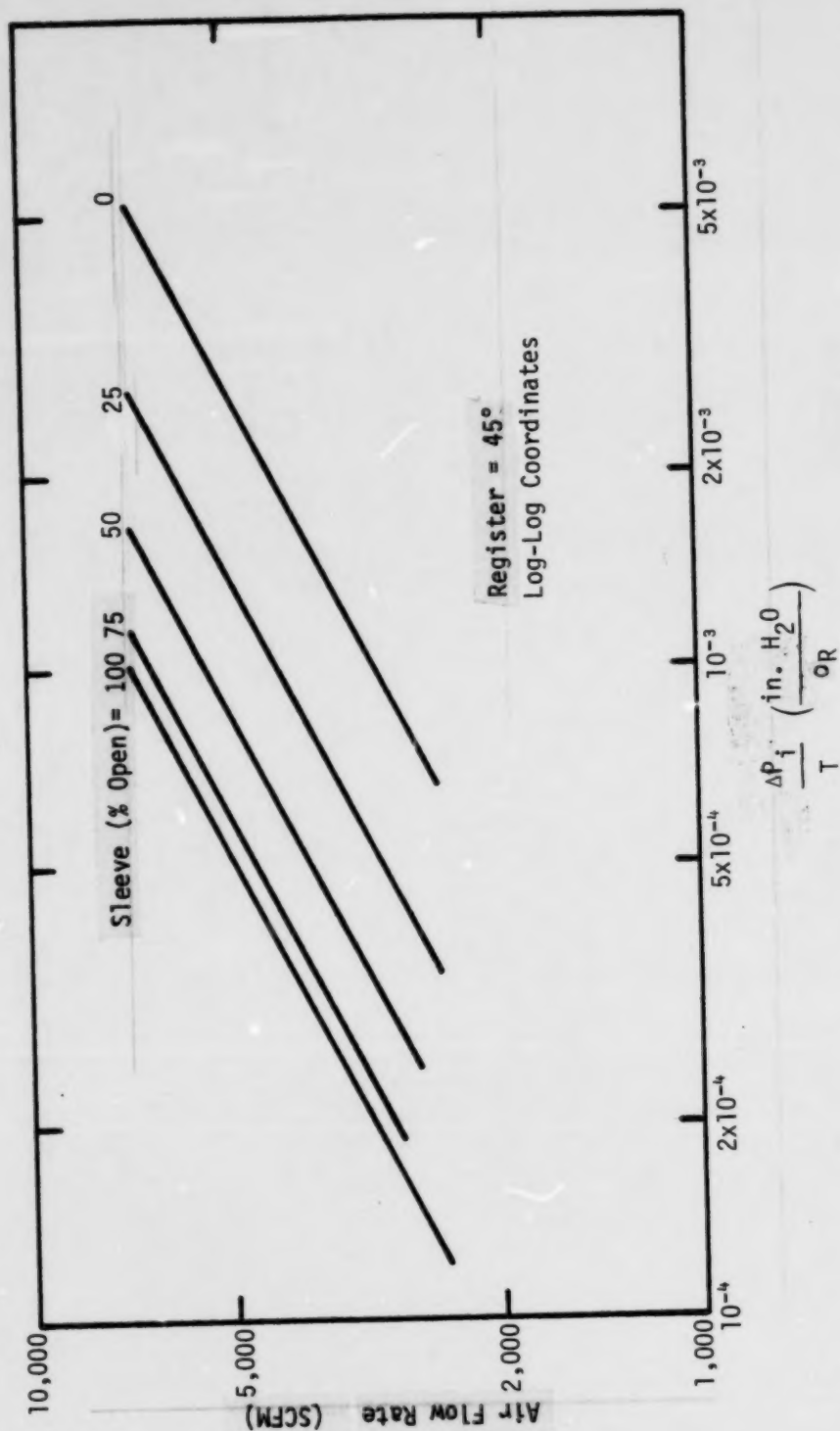


Figure 2-8. Outer Secondary Calibration.

The calibration in Figure 2-8 was conducted with the register at 45 degrees. Similar calibrations were conducted over a range of register positions with the sleeve fully open. Figure 2-9 shows the calibration constant determined from these tests as a function of register position. The calibration constant is invariant within the standard deviation range of the correlations over the normal range of register positions (30 degrees to 60 degrees).

Table 2-6 shows the outer secondary correlations for each sleeve position and an average correlation for all sleeve positions. The standard deviation for the average correlation is 10 percent which is considerably less than for the core air valve.

The windbox pressure drop was also correlated with the airflow rate over a range of sleeve and register positions. Due to the clearance between the sleeve and air hood (discussed above), the sleeve position had a minimal effect of register position. The correlation is as follows:

$$Q = (201601 - 1966 P_r) \left(\frac{\Delta P_{wb}}{T} \right)^{1/2} \quad (3)$$

where:

P_r = position of register (degrees from fully open).

This relationship is valid over the normal range of register positions (30 to 60 degrees) and illustrates the throttling effect of closing the register.

The register also provides swirl. The swirl angle in the burner throat was measured with a five-hole probe. Figure 2-10 shows the swirl as a function of register position. The data points were measured by traversing the probe on a horizontal line across the throat. The theoretical swirl angle was calculated assuming that the register channels all air in the direction of the vanes and conservation of angular momentum. This relationship is also shown in Figure 2-10. At low register settings (register vanes almost radial) the measured swirl angle is somewhat greater than the theoretical relationship. This is probably due to experimental error including uncertainty in register position and the traversing of the five-hole probe along a single line. At higher register settings the rate of increase of swirl angle with register position tapers off. This is probably due to leakage around the register vanes.

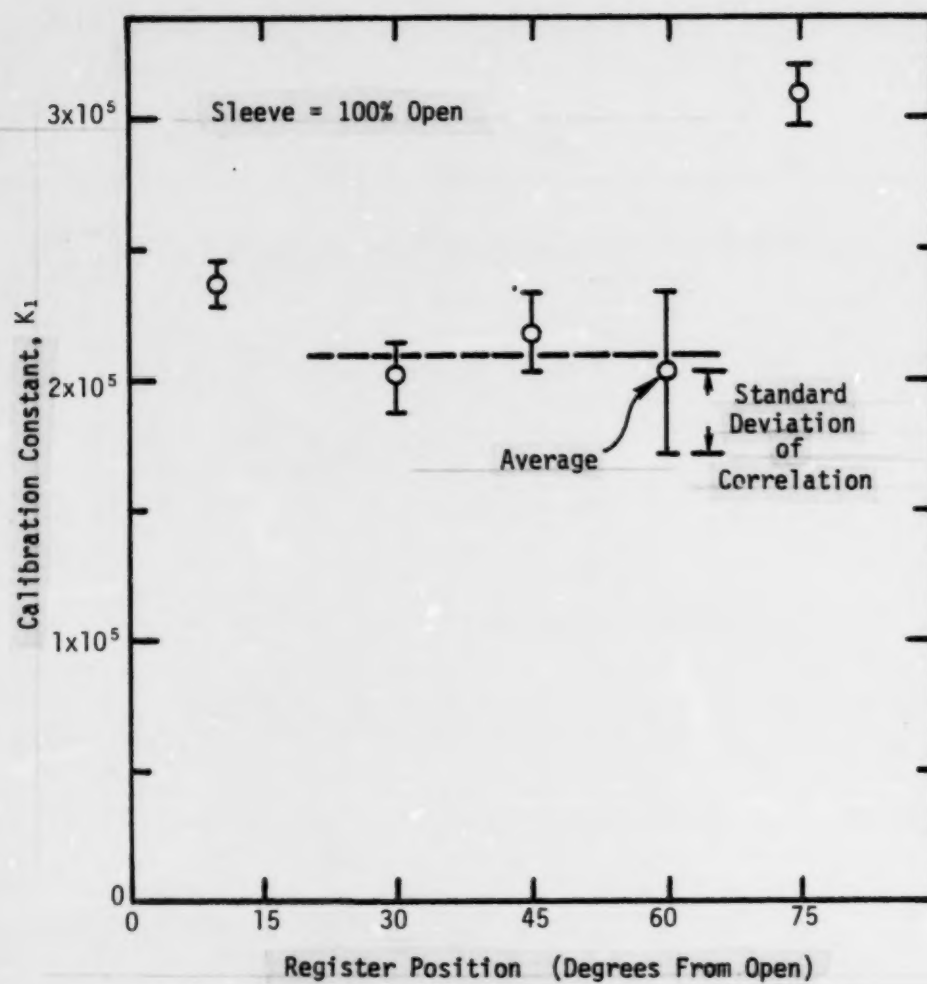


Figure 2-9. Effect of Outer Register on Calibration Constant, K_1 .

Table 2-6. Airflow Rate Correlations - Outer Secondary

Sleeve Position	EQUATION	DEVIATION
100% Open	$Q = 218726 (\Delta P_i / T)^{1/2}$	$\pm 6.9\%$
75% Open	$Q = 202582 (\Delta P_i / T)^{1/2}$	$\pm 0.6\%$
50% Open	$Q = 167958 (\Delta P_i / T)^{1/2}$	$\pm 7.0\%$
25% Open	$Q = 131795 (\Delta P_i / T)^{1/2}$	$\pm 2.4\%$
0% Open	$Q = 95653 (\Delta P_i / T)^{1/2}$	$\pm 7.6\%$
COMBINED RESULTS		
0 - 100% Open	$Q = (95955 + 1428 P_S) (\Delta P_i / T)^{1/2}$	$\pm 10\%$

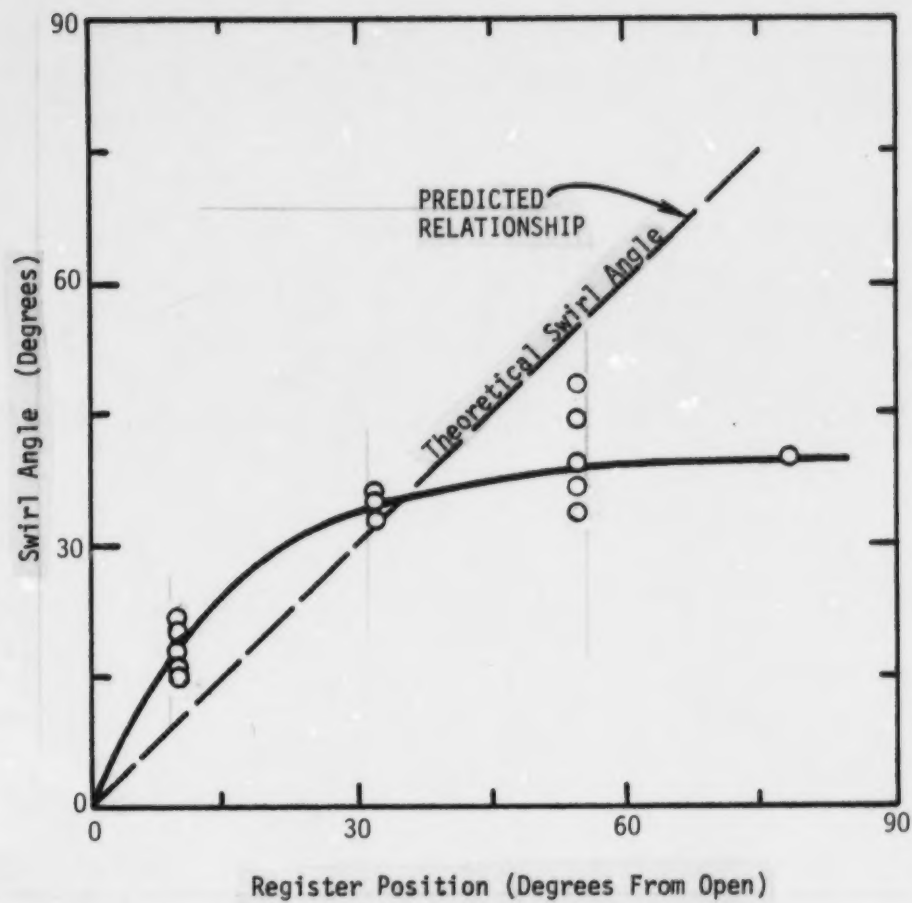


Figure 2-10. Swirl Angle in Outer Secondary.

The results in Figure 2-10 show that over the normal register operating range (30° to 60°) the register position has minimal effects on swirl angle. Thus, any changes in flame shape as register position is varied must be due to a redistribution of air among the burner passages.

Inner Secondary

The inner secondary was calibrated in the same manner as the outer secondary except that no swirl angle measurements were made. Figure 2-11 shows the relationship between pressure drop across the sleeve and air hood, air flow rate, and temperature for several sleeve positions. Due to mechanical interference, the sleeve could not be fully closed. As with the outer secondary, the clearance between the sleeve and air hood affected the calibration for sleeve positions greater than 75 percent open. The test results show essentially the same flow rate for sleeve positions of 75 and 100 percent open. The effect of register position is shown in Figure 2-12. As with the outer secondary, the calibration constant is not affected by register position over the normal operating range.

Table 2-7 shows the inner secondary correlations for each sleeve position and an average correlation for all sleeve positions. The standard deviation for the average correlation is 10 percent, the same as the outer secondary. The windbox pressure drop was correlated with register and sleeve positions with the following result:

$$Q = (0.64 + 0.0036 P_s) (931168 - 515 P_r) \left(\frac{\Delta P_{wb}}{T} \right)^{1/2} \quad (4)$$

where:

P_s = position of the sleeve (percent open)

Comparison of the correlations for the inner and outer secondaries (Tables 2-6 and 2-7, and Equations 3 and 4) shows that for similar settings and pressure drops, the air flow rate through the outer secondary is approximately twice as great as through the inner secondary. Thus, at the nominal burner design point, the indicated pressure signals on both secondaries are about equal. This will simplify burner adjustments.

Tertiary Ports

The effective open area of the perforated plate used for airflow rate measurement on each tertiary port is independent of control valve position.

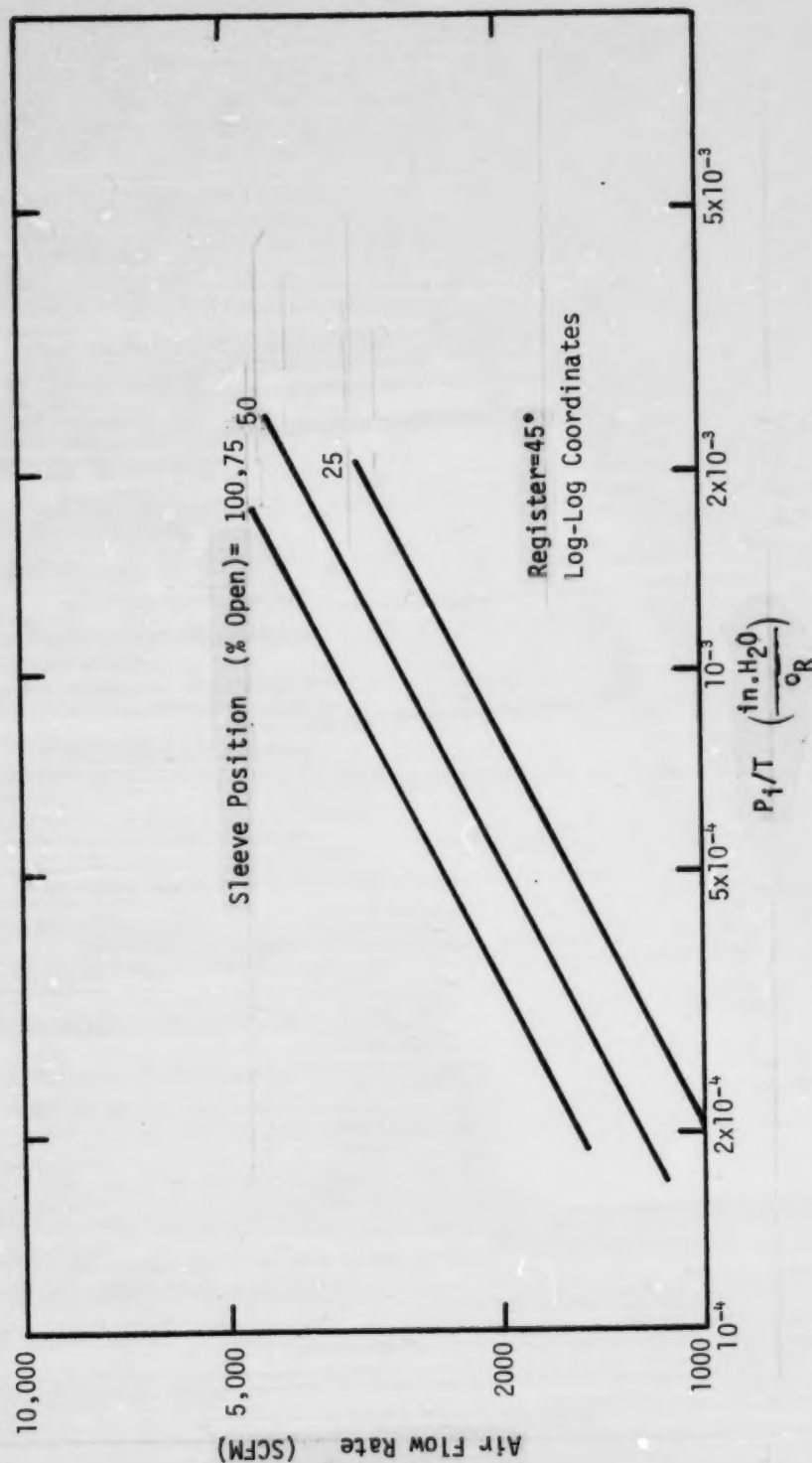


Figure 2-11. Inner Secondary Calibration.

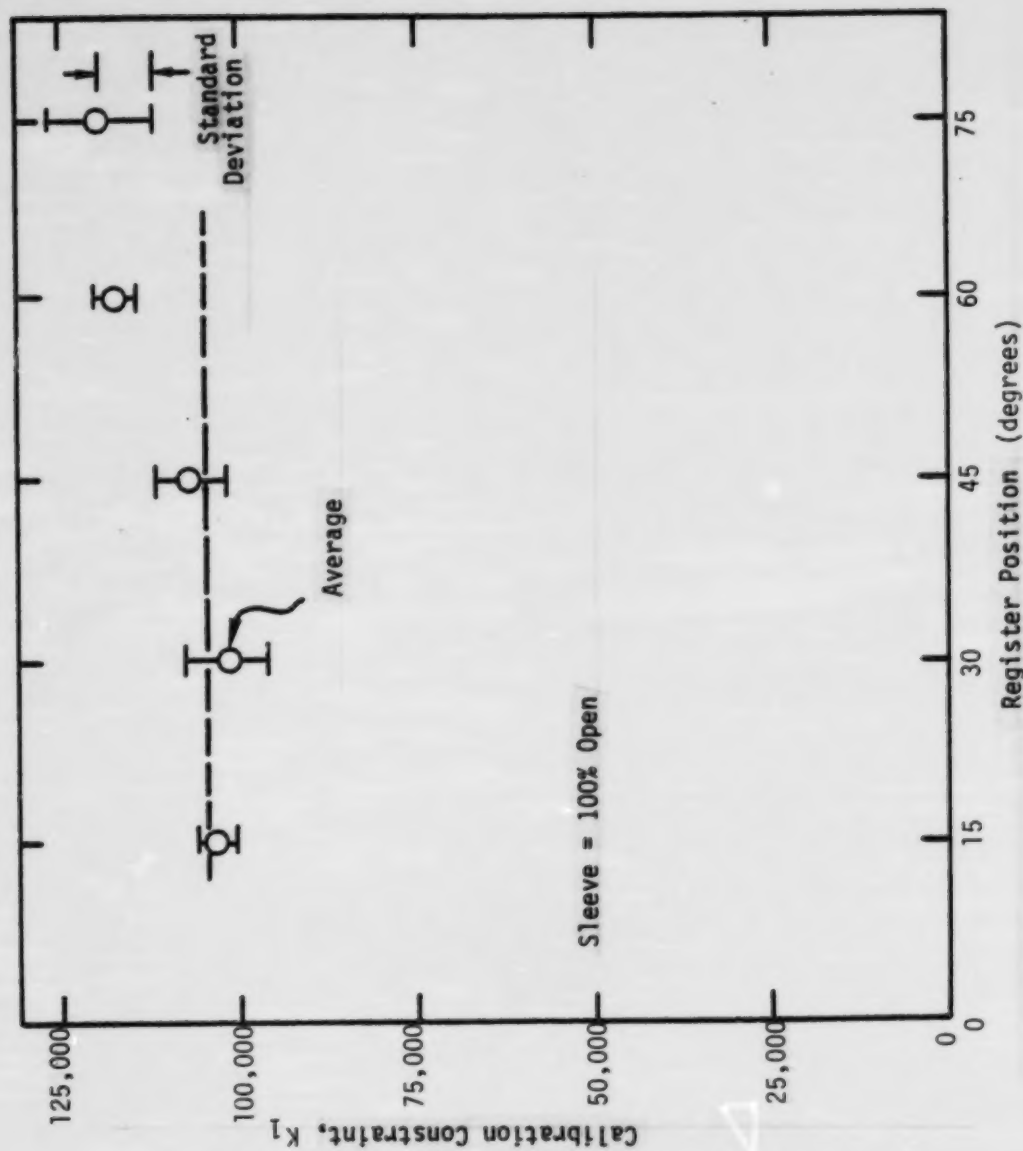


Figure 2-12. Effect of Inner Register on Calibration Constant, K_1 .

Table 2-7. Airflow Rate Correlations - Inner Secondary

Sleeve Position	EQUATION	DEVIATION
100% Open	$Q = 107374 (\Delta P_i/T)^{1/2}$	$\pm 4.7\%$
75% Open	$Q = 107439 (\Delta P_i/T)^{1/2}$	$\pm 1.1\%$
50% Open	$Q = 87821 (\Delta P_i/T)^{1/2}$	$\pm 7.7\%$
25% Open	$Q = 69904 (\Delta P_i/T)^{1/2}$	$\pm 6.4\%$
COMBINED RESULTS		
25-75% Open	$Q = (50853 + 751 P_s) (\Delta P_i/T)^{1/2}$	$\pm 10\%$

Thus, a single calibration should be sufficient to fully characterize operation. To verify this one tertiary port assembly was calibrated at several control valve positions. The calibrations were found to be constant, independent of control valve position, within experimental error. In addition, the calibrations were found to be independent of the following parameters:

- Location within the windbox
- Manufacturing tolerances
- Pressure tap locations
- Tertiary port exit diameter
- Air temperature
- Windbox pressure

Figure 2-13 shows the average calibration and data from the four tertiary port assemblies.

The position of the control valve determine the overall flow restriction in the tertiary air passage. Consequently, the relationship between ΔP_{wb} , Q and T depends on the control valve position, P_v . This is illustrated in Figure 2-14 where the flow rate through one tertiary port is plotted against control valve position for several values of ΔP_{wb} . Note that for constant ΔP_{wb} , the airflow rate is approximately linearly related to control valve position. A crossplot of these data (Figure 2-15) shows the expected relationship between airflow rate and $\Delta P_{wb}/T$ for constant control valve positions. The correlations for each control valve position and the overall correlations are shown in Table 2-8.

2.2.4 Summary

The calibrations discussed above are summarized in Table 2-9. These relationships may be used to determine the burner settings necessary to establish specific flow rates through each burner passage or to evaluate the flow rates from the indicated pressure drops across the flow measurement devices.

The burner setting for staged and unstaged operation at the full load operating point have been calculated and the results are shown in Table 2-10. It is assumed that the sleeve on the outer secondary is left fully open and the flow rates through the other burner passages are balanced by their respective

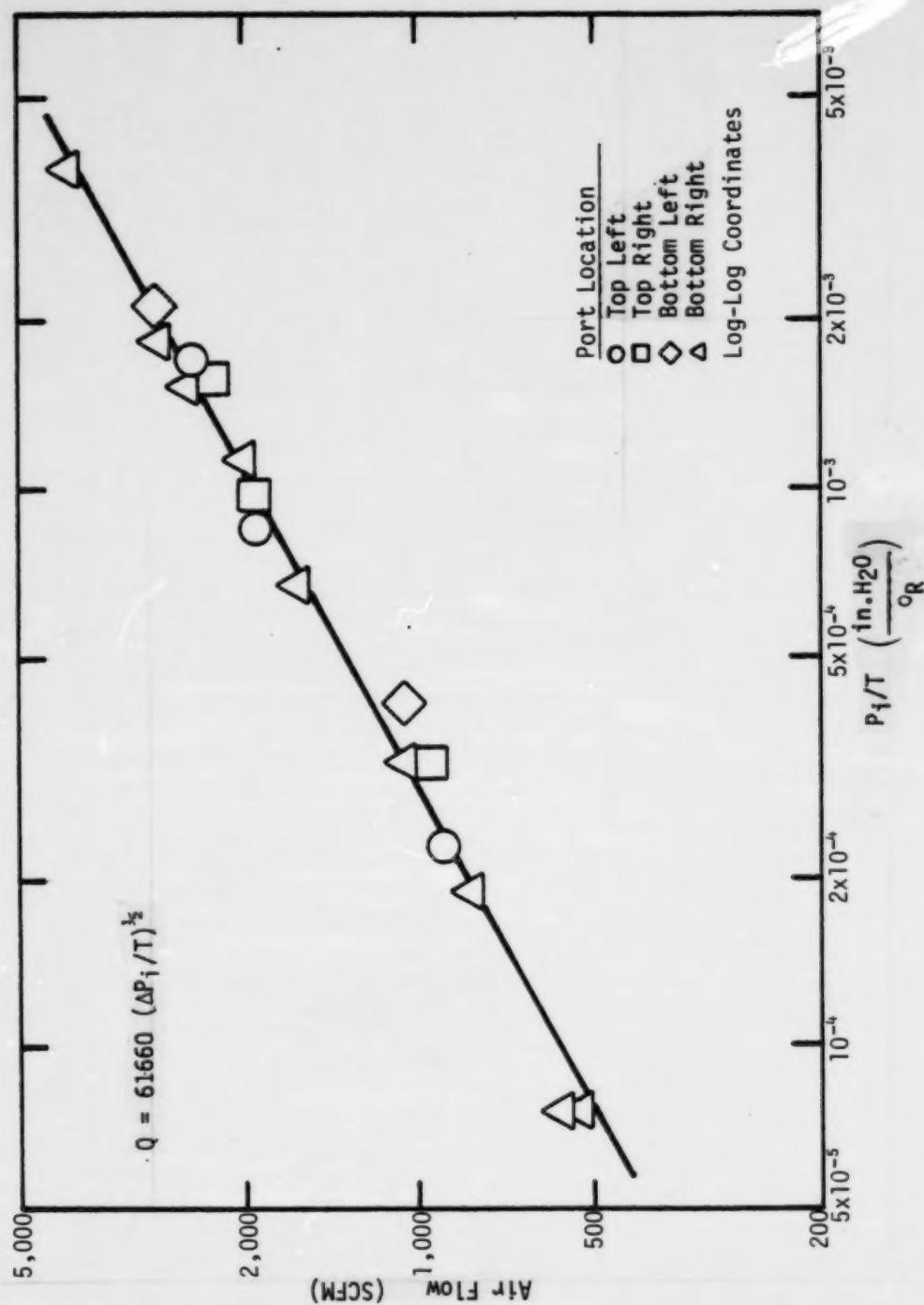


Figure 2-13. Tertiary Port Calibration.

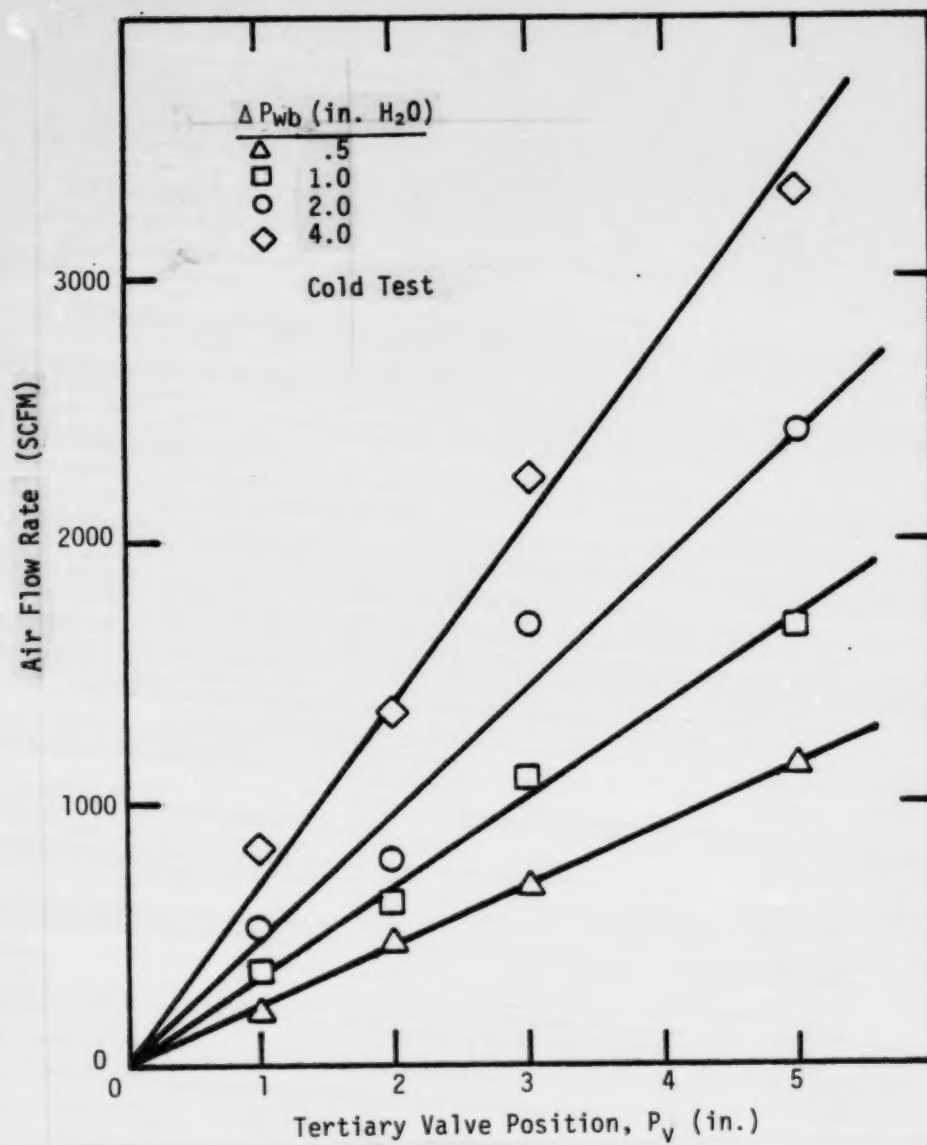


Figure 2-14. Effect Of Control Valve Position On Air Flow Rate Through A Tertiary Port.

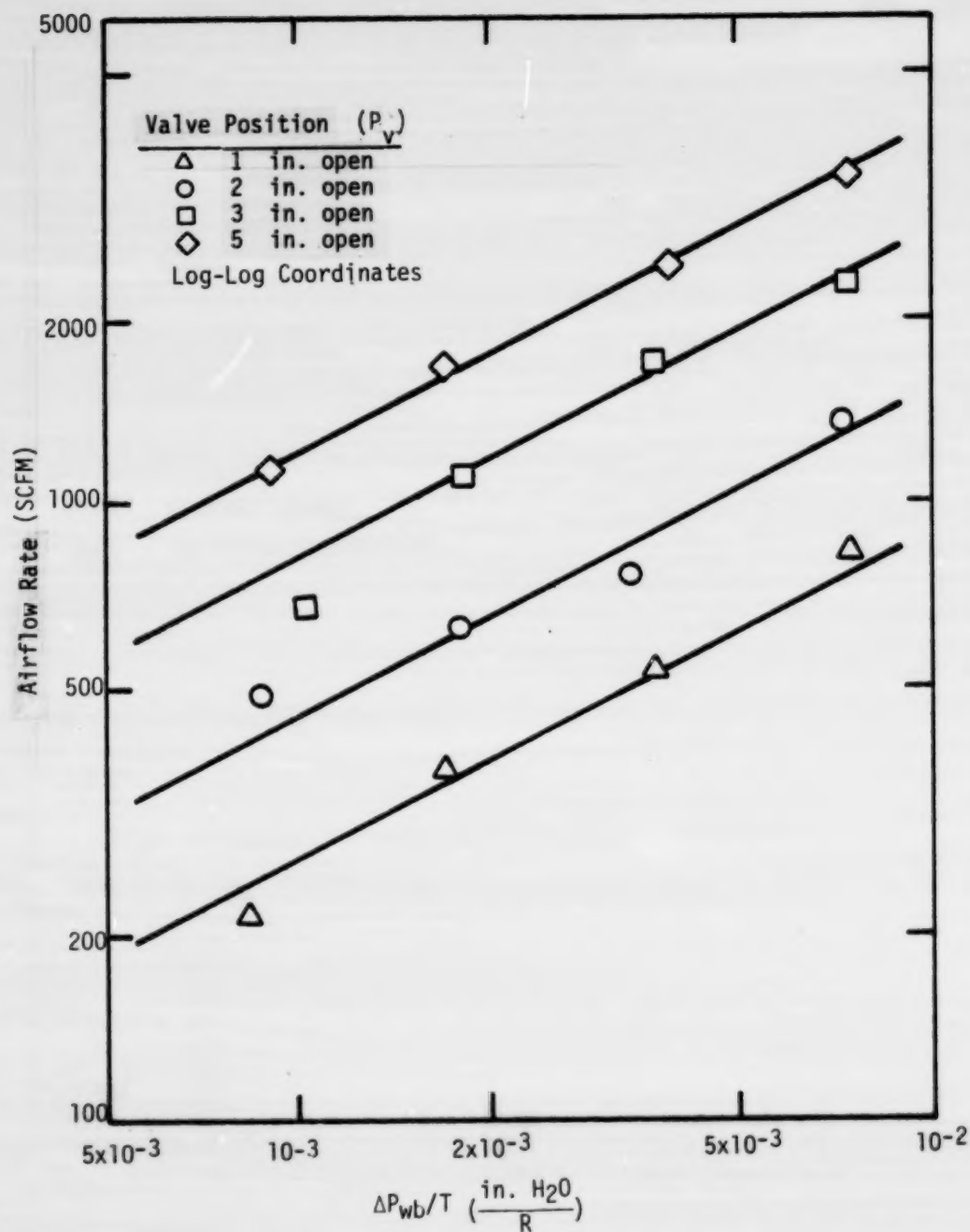


Figure 2-15. Effect of Windbox Pressure Differential on Airflow Rate Through a Tertiary Port.

Table 2-8. Airflow Rate Correlations - Tertiary

Valve Position	EQUATION	DEVIATION
1 in. Open	$Q = 8668 (\Delta P_{wb}/T)^{1/2}$	$\pm 9.5\%$
2 in. Open	$Q = 15095 (P_{wb}/T)^{1/2}$	$\pm 12.5\%$
3 in. Open	$Q = 26263 (P_{wb}/T)^{1/2}$	$\pm 10.7\%$
5 in. Open	$Q = 38635 (P_{wb}/T)^{1/2}$	$\pm 3.0\%$
COMBINED RESULTS		
2-5 in. Open	$Q = (7609 P_v + 1300) (\Delta P_{wb}/T)^{1/2}$	$\pm 15\%$

Table 2-9. Calibration Summary

BURNER PASSAGE	$Q = (\quad) \left(\frac{\Delta P_i}{T} \right)^{1/2}$	$Q = (\quad) \left(\frac{\Delta P_{wb}}{T} \right)^{1/2}$	UNITS
CORE	18500 - 182 P_v	18500 - 182 P_v	P_v = Degrees from Full Open
OUTER SECONDARY	96000 + 1430 P_s	202,000 - 1970 P_r	P_r = Degrees from Full Open
INNER SECONDARY	509 + 751 P_s	~~$(0.64 + 0.0036 P_s)$ $(93200 - 515 P_r)$~~	P_r = Degrees from Full Open P_s = Percent Open
TERTIARY	60700	7610 P_v + 1300	P_v = Inches Open

Note

Q = SCFM
 ΔP_{wb} = in. H_2O
 ΔP_i = in H_2O
 T = °R

Table 2-10. Calculated Burner Operating Points.

PASSAGE	BURNER		AIRFLOW (%T.A.)(SCFM)	ΔP_{wb} (In. H ₂ O)	ΔP_1 (In. H ₂ O)
	SPECIFIED	SETTINGS CALCULATED			
STAGED					
CORE	$P_v = 45^\circ$		2.6 297	0.88	0.88
OUTER SECONDARY	$P_r = 35^\circ P_s = 100\%$		33.3 3830	0.88	0.27
INNER SECONDARY	$P_r = 45^\circ$	$P_s = 87\% \text{ Open}$	16.7 1921	0.88	0.30
TERTIARY	—	$P_v = 6.4 \text{ In. Open}$	12.5* 1438*	0.88	0.59
UNSTAGED					
CORE	$P_v = 45^\circ$		5.2 594	3.52	3.52
OUTER SECONDARY	$P_r = 35^\circ P_s = 100\%$		66.7 7667	3.52	1.09
INNER SECONDARY	$P_r = 45^\circ$	$P_s = 87\% \text{ Open}$	33.3 3833	3.52	1.15
TERTIARY	—	—	0 0	—	—

CONDITIONS

Firing Rate = 69×10^6 BTU/HR (Full Load)
 Excess Air = 20%
 Primary Stoichiometry = 20% TA
 Burner Zone Stoichiometry = 70%

Windbox Flowrate = 11,500 SCFM (Core Neglected)
 Windbox Temperature = 600°F
 * Per Port

control devices. The outer secondary settings and the specified flow rate determine the windbox pressure differential. The positions of the control devices for the other passages are calculated from this windbox pressure differential and the specified flow rates. Since the flow rate through the core is always small, it is calculated separately based on the normal setting (45°) and the windbox pressure differential.

The windbox pressure differential for staged operation is much smaller than for unstaged operation. This is due to the reduced airflow rates through the burner throat under staged conditions and the assumption that the outer secondary sleeve remains fully open. This also requires the tertiary control valves to be almost fully open. The indicated pressure differentials are in the range of 0.3 to 0.9 in. H₂O and may be measured with either an inclined manometer or a magnahelic gauge. If the outer secondary sleeve is partially closed and the other control devices are readjusted to balance the flow rates, the windbox and indicated pressure differentials will be higher.

Figure 2-16 shows the prototype DMB pressure drop over the host boiler operating range. The pressure drop for the original equipment Intervane Burners is also shown. For unstaged operation, the prototype DMB has approximately the same pressure drop as the Intervane Burner. Thus, the low NO_x burners are compatible with the original equipment fans. Under staged conditions, the prototype DMB pressure drop is considerably lower than the original equipment burners. However, the pressure drop can be increased by closing the sleeves around the secondary registers and readjusting the tertiary port control valves. In summary, the low NO_x burners are compatible with the host boiler fan characteristics in both staged and unstaged operating modes.

2.3 Coal-Fired Tests

2.3.1 Unstaged Tests in the Old LWS

The second phase, Unstaged Tests, includes firing the burner over the host boiler operating range to verify that the field burners can operate unstaged if a problem with the tertiary air system develops. The prototype burner was fired over a range of burner settings, loads and excess air with the Utah coal to allow direct comparison with the previous DMB and Intervane Burner test results. The host (Indiana) coal will be fired in a subsequent test series. Table 2-11 compares the characteristics of Utah 2, 3 and the host coal. All three fuels are

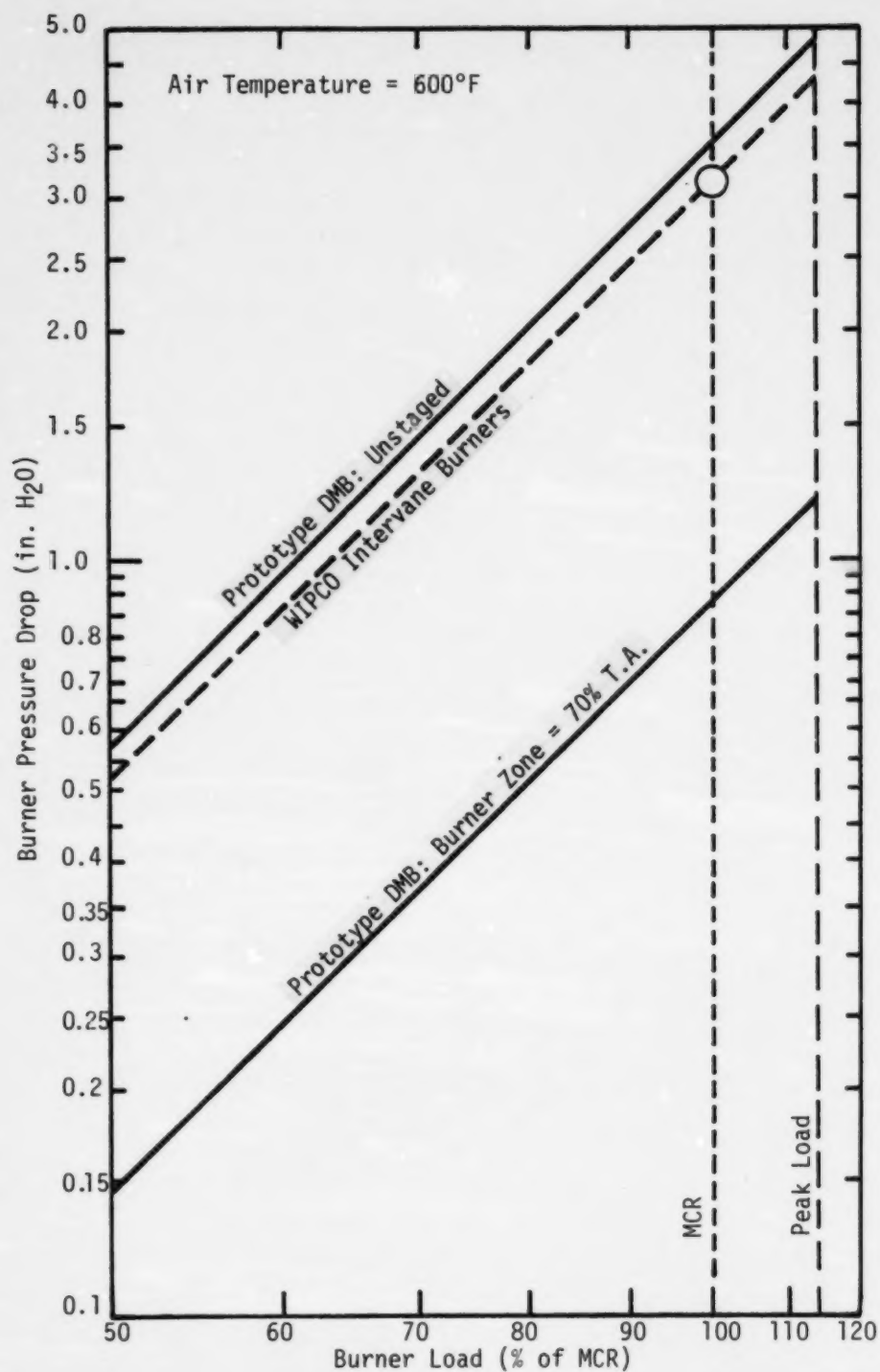


Figure 2-16. Prototype DMB Pressure Drop Over Host Boiler Operating Range.

Table 2-11. Coal Composition Comparison.

	UTAH-II		UTAH-III		INDIANA-(HOST)	
	AS REC'D	DRY	AS REC'D	DRY	AS REC'D	DRY
PROXIMATE ANALYSIS (%)						
MOISTURE	7.41	—	4.58	—	13.03	—
ASH	8.83	9.54	8.76	9.18	10.14	11.66
VOLATILE MATTER	38.84	41.94	37.87	39.69	36.08	41.49
FIXED CARBON	44.92	48.52	48.79	51.13	40.75	46.85
ULTIMATE ANALYSIS (%)						
MOISTURE	7.41	—	4.58	—	13.03	—
CARBON	66.89	72.24	69.80	73.15	61.30	70.48
HYDROGEN	5.33	5.75	5.19	5.44	4.36	5.01
NITROGEN	1.43	1.55	1.52	1.59	1.30	1.49
SULFUR	0.70	0.76	0.68	0.71	2.87	3.30
ASH	8.83	9.54	8.76	9.18	10.14	11.66
OXYGEN (BY DIFF)	9.41	10.16	9.47	9.92	6.97	8.02
CALORIFIC CONTENT (BTU/LB)	11877	12827	12333	12924	11216	12896

high volatile bituminous coals and should result in comparable burner performance based on the results of the development DMB tests.

The test conditions were adjusted to match the host load schedule. Figure 2-17 shows the load schedule for all four burners in service (based on the boiler design specifications) and for two burners in service (based on the results of a single mill test). Since the host boiler normally operates with all burners in service, the boiler design specifications were used in these tests.

The following burner parameters are adjustable on the prototype burner:

- Inner Register*
- Outer Register*
- Inner Sleeve
- Outer Sleeve*
- Core Air Valve
- Nozzle Setback*
- Primary Exit Area
- Tertiary Exit Area

The parameters designated with asterisks (*) were evaluated at MCR conditions. The optimum settings were then used for variable load and excess air tests. The results are discussed below.

The inner register effect, depicted in Figure 2-18, was to increase NO emissions as the swirl increased until a flameout occurred with the register setting in excess of 55 degrees of swirl. Very little effect was noted on the flame shape or stability (within the range of normal operation). The rise in NO emissions was commensurate with the anticipated behavior since increased swirl causes more rapid and complete fuel/air mixing which is known to produce higher levels of NO. However, the flameout at high swirl levels is not consistent with this explanation unless the significant flow restriction of the high swirl setting is considered. The increased resistance to flow within the inner secondary forces air to the outer secondary leaving insufficient tangential momentum in the burner to stabilize the flame. From these results, 45 degrees was identified as the most satisfactory inner register setting since it allowed sufficient swirl for flame stabilization while producing an acceptable inner register pressure drop.

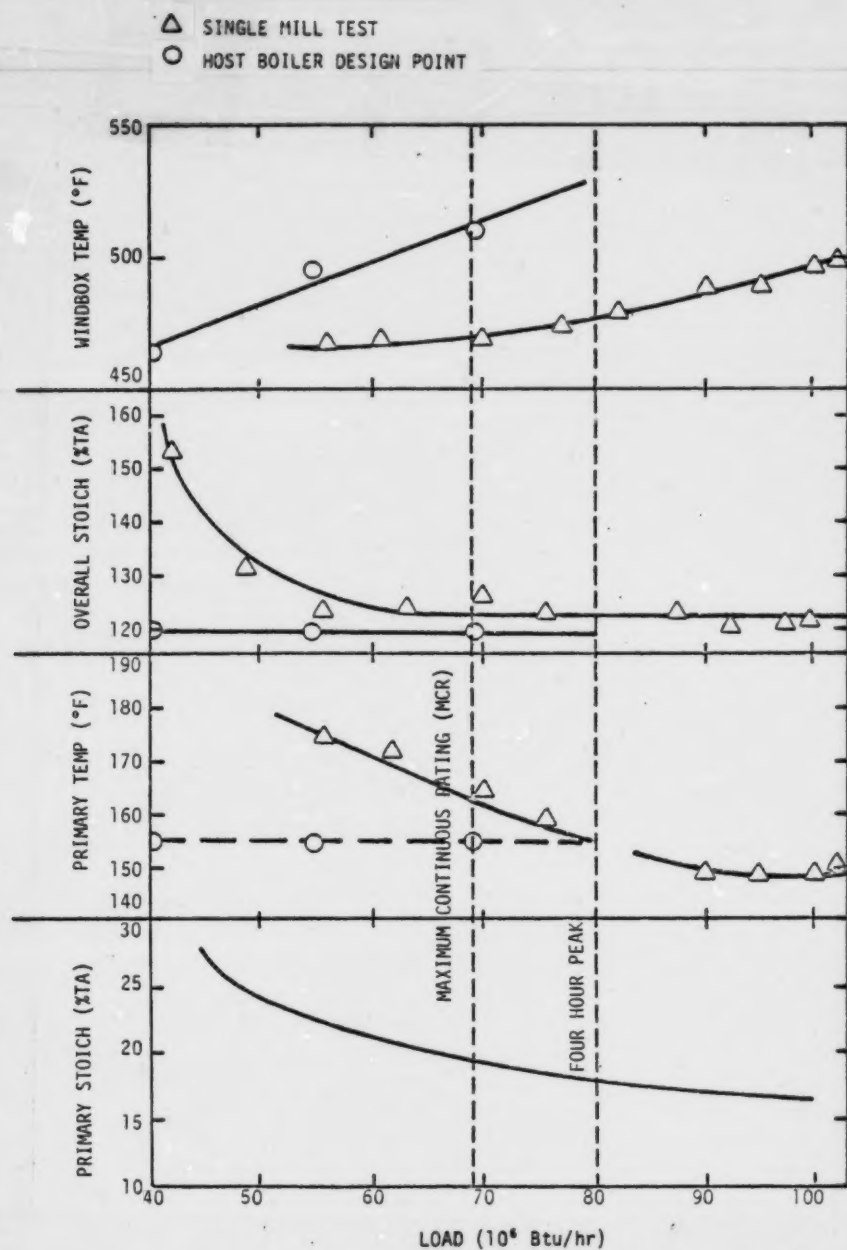


Figure 2-17. Illinois Host Site Load Schedule.

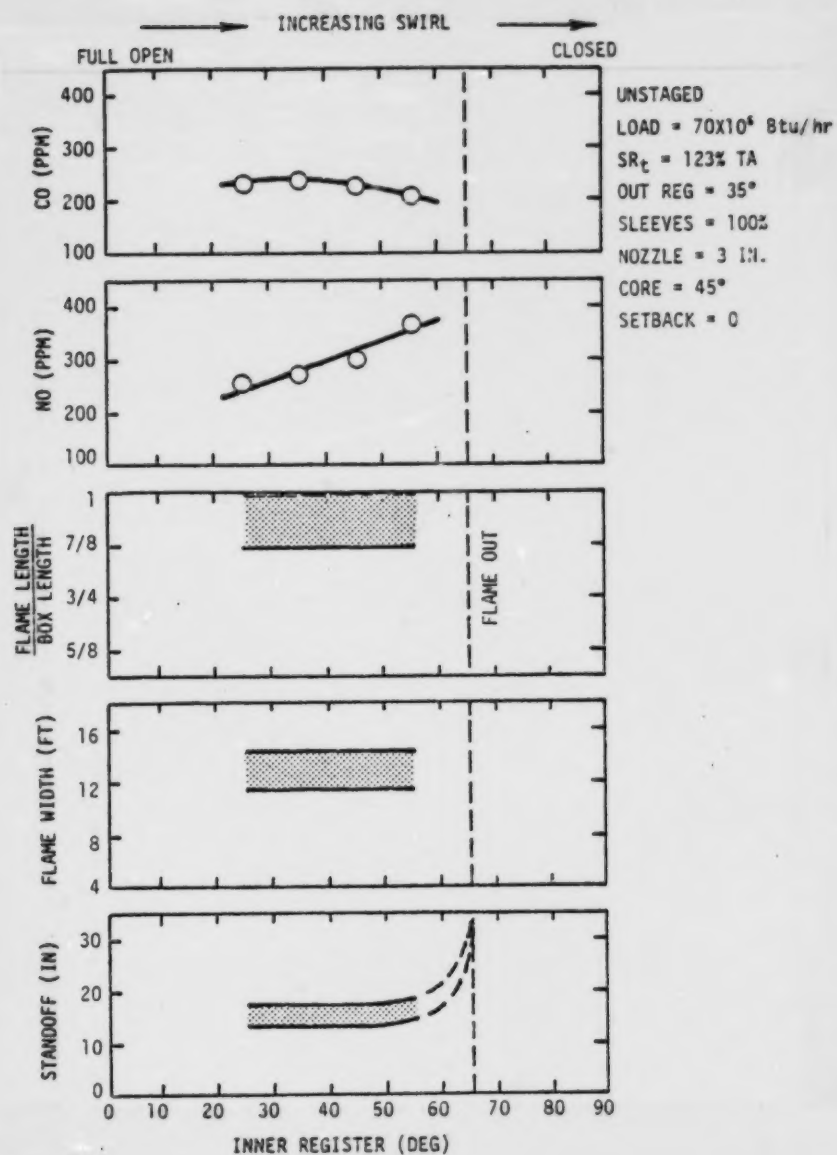


Figure 2-18. Effect of Inner Register.

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In contrast to the inner register, the outer register has a pronounced effect on flame shape but little effect on emissions (see Figure 2-19). Increasing the outer swirl produced a shorter, wider flame until the flame became attached to the furnace wall adjacent to the quarl with the register setting at 55 degrees. Once the flame was wall-attached, it was necessary to adjust the outer register to 15 degrees in order to effect a transition back to the normal condition. Reducing the swirl past the 15 degrees position resulted in a flameout. The flameout at low outer swirl is attributed to the same mechanism that resulted in the flameout at high inner swirl. As the outer swirl is decreased, the outer secondary flow restriction decreases, which diverts more air from the high swirl inner secondary until insufficient tangential momentum remains to stabilize the flame at the burner exit.

The minimal effect of outer register on emissions suggests that the outer secondary air does not mix with the primary and inner secondary air until after the NO has been substantially formed. Two operating points were identified for further testing. An outer register setting of 35 degrees resulted in a more desirable flame shape, but wall-attached flames were occasionally observed at that setting. Fifteen degrees was also selected since this was the highest swirl setting at which there was no indication of a wall-attached flame.

Having examined both registers, the next step was to determine the effect of the burner air sleeves. The effect of the outer sleeve is shown in Figure 2-20. Beginning with the sleeve fully open, closing the sleeve to 75 percent open had no effect on emissions, but caused the flame to become narrower. Further closing of the sleeve to 50 percent open resulted in a flameout. The narrower flame with the partially closed sleeve is due to diversion of air from the outer air envelope to the flame interior. This also causes an increase in the inner secondary velocity until the flame is pushed out of the burner. It was determined at this time that further characterization of the outer sleeve required an increase in the inner swirl both to hold the flame close to the quarl and to counteract the air diversion caused by closing the outer sleeve.

With the inner register setting at 55 degrees, it was possible to close the outer sleeve to 25 percent open without causing a flameout (see Figure 2-21). Under these conditions the only effect of the outer sleeve was to raise the NO emissions level. This was attributed to the increased air flow rate in the high swirl inner secondary resulting in rapid fuel/air mixing at the burner exit.

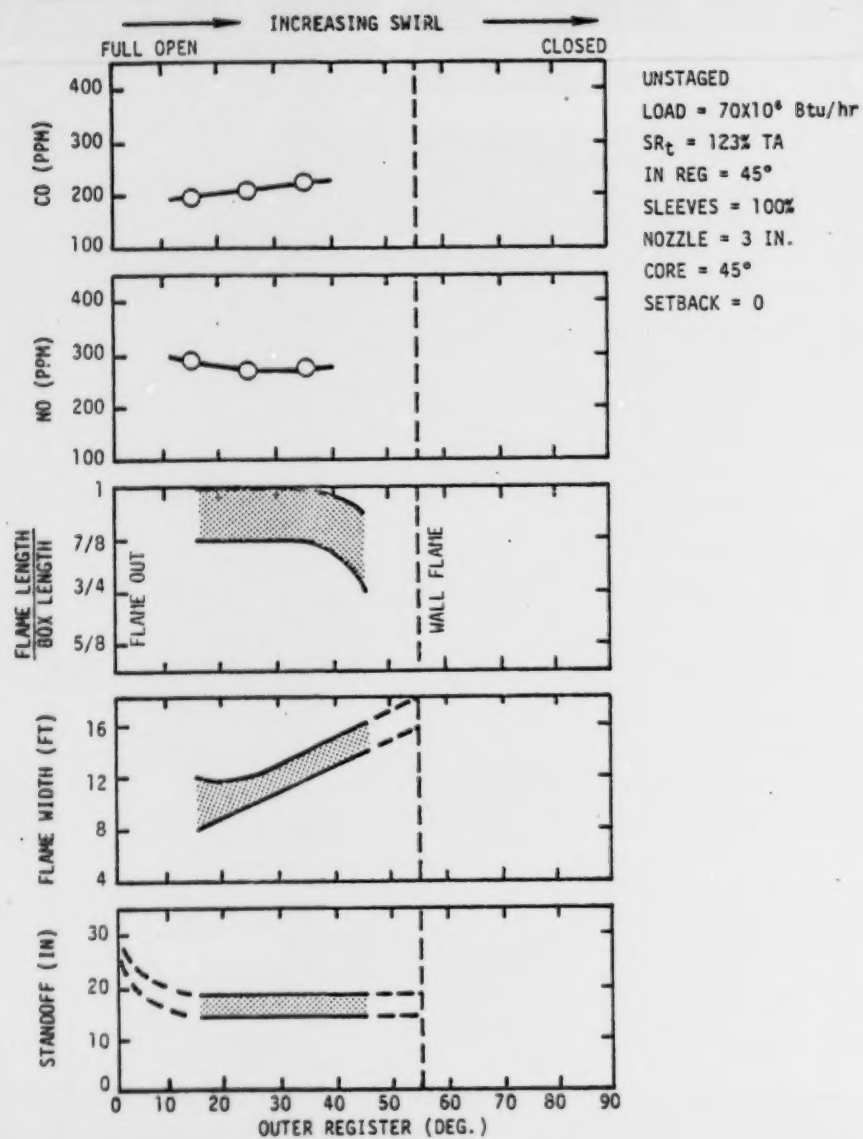


Figure 2-19. Effect of Outer Register.

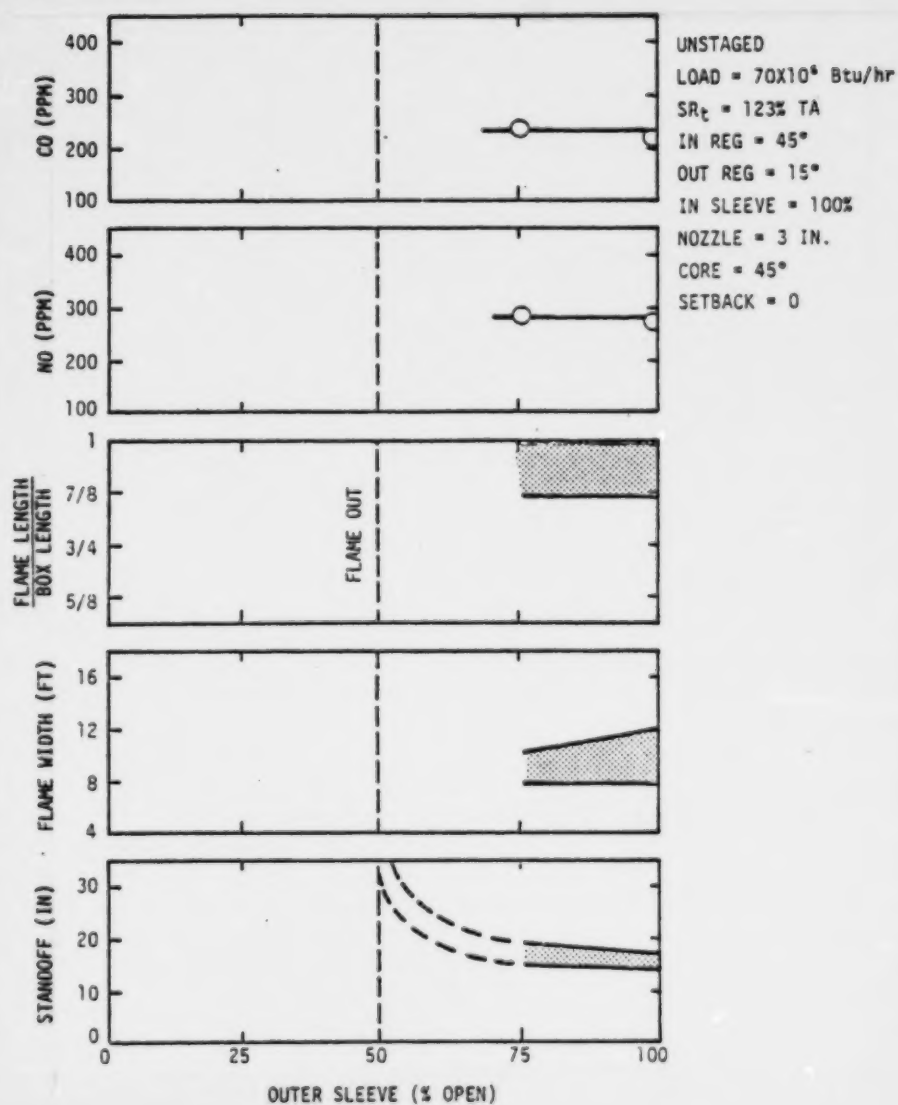


Figure 2-20. Effect of Outer Sleeve (Inner Register = 45°).

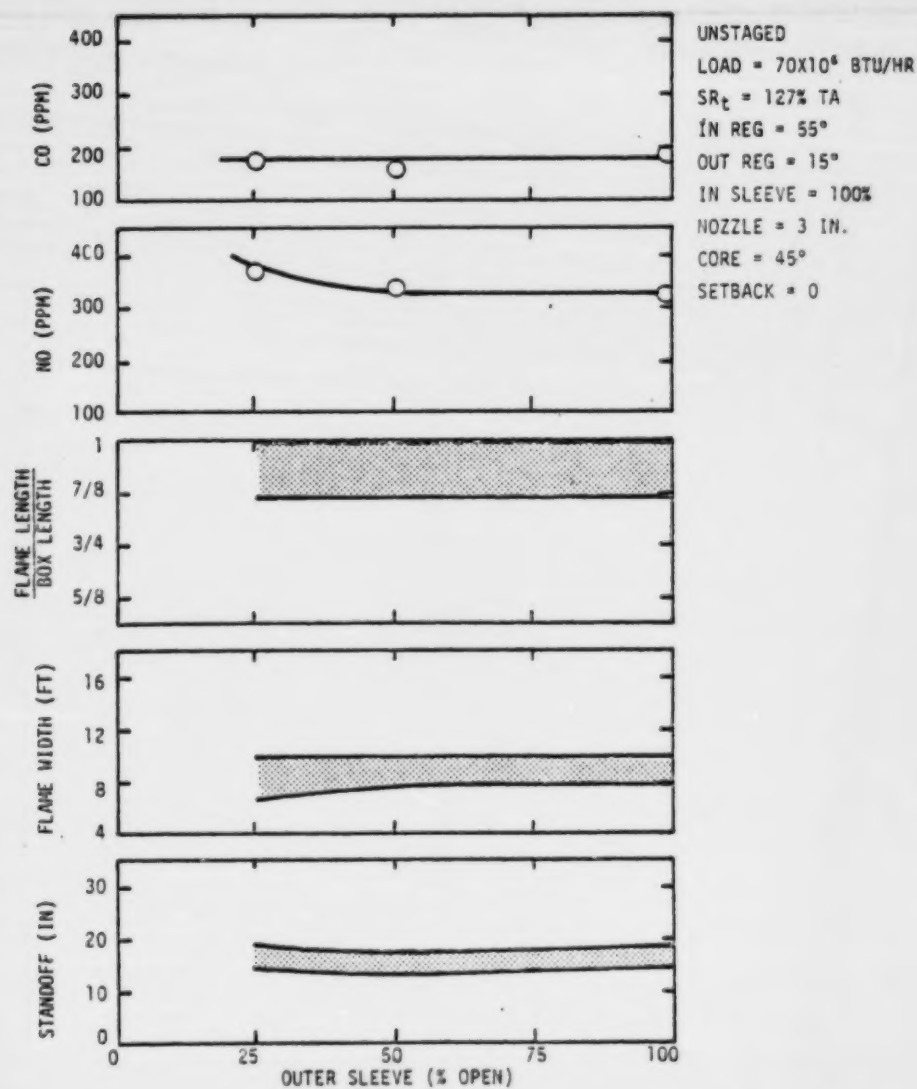


Figure 2-21. Effect of Outer Sleeve (Inner Register = 55°).

The flame width was only slightly affected by the outer sleeve. The 100 percent open position was selected as the most satisfactory operating condition primarily because it allowed maximum flexibility in operation and produced a lower burner pressure drop.

Table 2-12 summarizes the ranges of burner variables investigated and their effects and lists the operating point selected for the variable load tests. The burner was tested over a 70 to 100 x 10⁶ Btu/hr load range using the host boiler operating conditions in Figure 2-17. The results of these tests shown in Figure 2-22 exhibit no influence of load on NO except for the 70 x 10⁶ Btu/hr case. This is similar to the Intervane Burner performance as shown in Figure 2-23. The test results for both burners show that NO is independent of load where the primary stoichiometry increases (as load decreases). It is suspected that this is actually an effect of primary velocity (which influences the primary/secondary mixing rates) rather than primary stoichiometry per se.

Another important observation can be made from Figure 2-23. Note that at the overall stoichiometry employed for the majority of the tests ($\approx$ 123 percent T.A.) the burner is operating in the "knee" region of the CO curve. Therefore slight variations in the stoichiometry, which might be caused by disturbances in coal feed rate, or other perturbations, could cause the operating point to shift around the knee. This may partially explain the spontaneous flameouts, transitions to wall-attached flames and inconsistent flame shapes observed throughout the test series.

The observations noted in the preceding paragraph indicated that a change in one of the burner parameters was required. The stability problem and the observation of a 15 to 16-inch flame standoff suggested that changing the primary setback might be advantageous for two reasons. First, changing the setback would move the coal introduction point further into the quarl, and second, earlier mixing of the primary and inner-secondary air streams should aid in flame stability.

The effect of changing the setback from 0 to 4 inches is illustrated in Figure 2-24. The reduced CO, increased NO, and the observation of more consistent burner performance were initial indications that the increased setback had improved stability. Note, however, that no noticeable change occurred in the flame standoff distance and that the flame shape was unaffected. Excess air

Table 2-12. Summary of Burner Variables.

Parameter	Experimental Range	Operating Point for Load Variation Tests	Effect
Core	—	45°	—
Inner Register	25-65°	45°	NO, Stability
Outer Register	0-55°	35°	Flame Shape
Inner Sleeve	—	100%	—
Outer Sleeve	25-100%	100%	Air Distribution
Primary Velocity (Core Nozzle Pos.)	0-3 in.	3 in.	Stability
Tertiary Exit Area (Port Diameter)	—	12 in.	—

PROTOTYPE BURNER

SETBACK = 0 IN.
 INNER REG = 45°
 OUTER REG = 35°
 SLEEVES = 100% OPEN
 CORE = 45°
 NOZZLE = 3 IN.

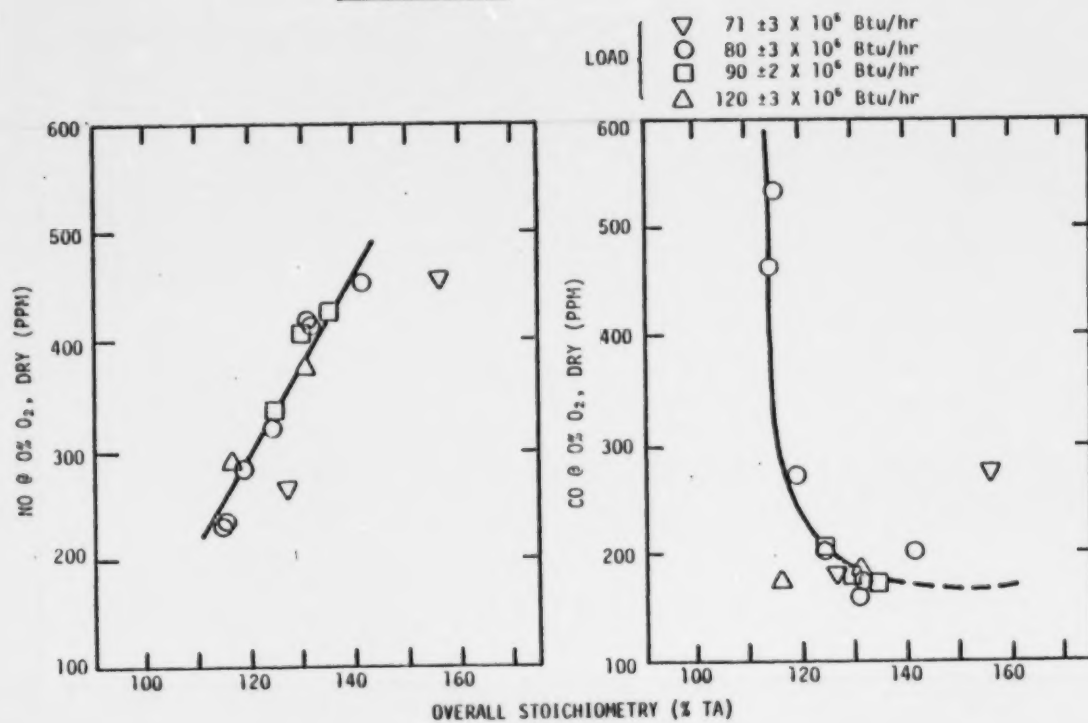


Figure 2-22. Effect of Load at Setback = 0.

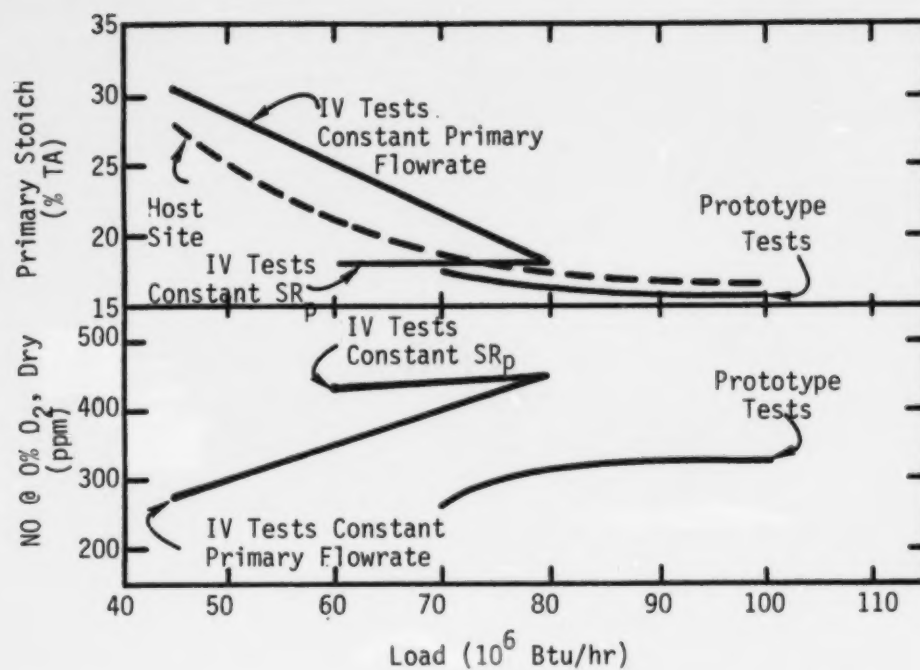


Figure 2-23. Intervane and Prototype Burner Load Effects.

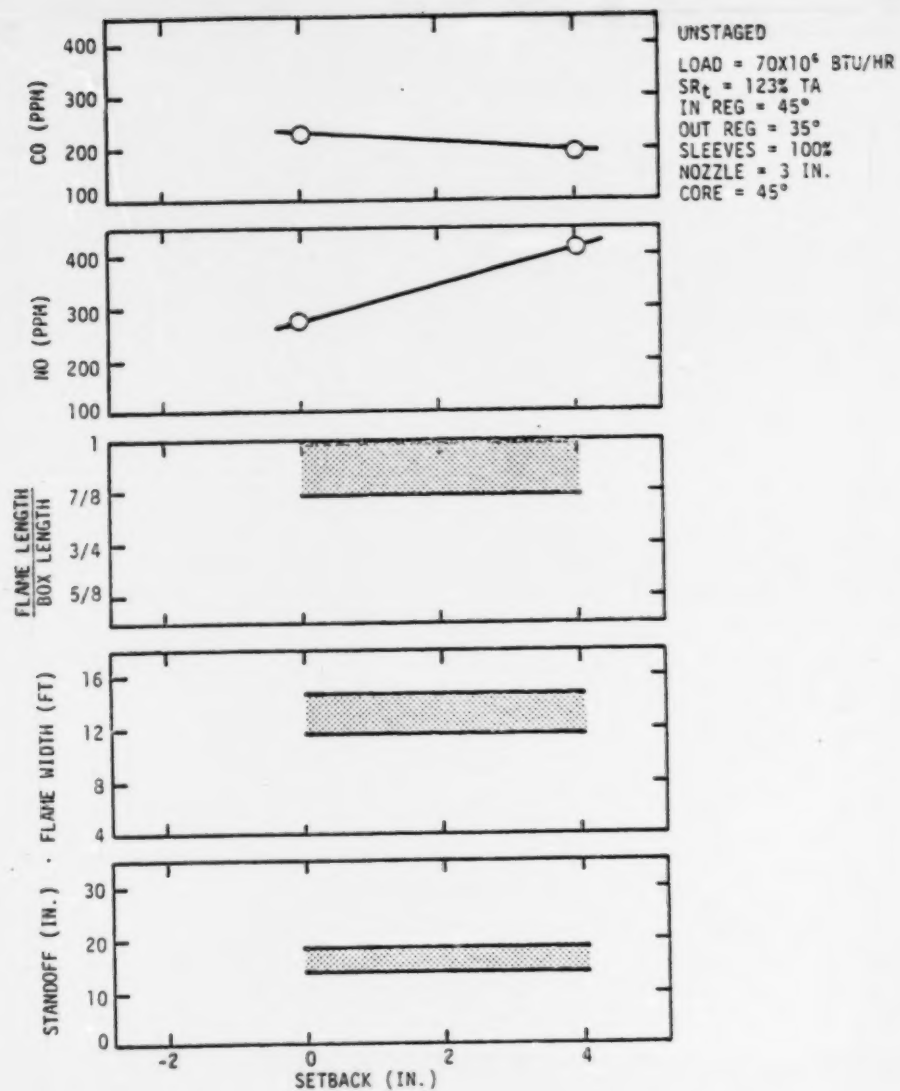


Figure 2-24. Effect of Nozzle Setback.

variations at 4-inch setback, shown in Figure 2-25, verified that the knee of the CO curve was shifted to lower excess air. Hence, the operating point of 118-123 percent T.A. is sufficiently stable that mill and other perturbations do not force the burner into unstable or high CO operating conditions.

Several other points can be made regarding the prototype burner from Figure 2-25 and additional test information. Note that the CO levels are lower for the prototype burner than for the Intervane with the burners tested at similar conditions. Also, unstaged NO emissions are lower at low excess air levels for the prototype. This is attributed to the larger throat diameter on the prototype resulting in lower velocity and slower mixing. Smoke levels were comparable for both burners.

It should, however, be noted that this prototype DMB's geometrical configuration has not been optimized. Since this design is based on Foster Wheeler's commercial hardware, which has been adapted to meet DMB velocity and flow criteria, further geometrical changes may be necessary to obtain optimum NO and CO performance with acceptable stability. Among the differences between this prototype and EER's previous experimental DMBs are:

<u>Prototype</u>	<u>Experimental DMBs</u>
Registers for swirl control	Swirl Vanes
Annular coal nozzle with tangential inlet	Axial coal nozzle with or without swirl
Open coal nozzle outlet with adjustable velocity feature	Impeller/swirler at nozzle outlet, fixed velocity
Medium quarl depth	Long quarl depth

It is reasonable and prudent to assume that these differences can result in NO and CO performance which are also different. The prototype results were obtained with an initial geometry which is likely to be non-optimum. Consequently, as part of the subsequent test program, the prototype's geometrical and flow parameters will be varied to determine the configuration which provides NO, CO and stability performance.

2.3.2 Staged Tests in the Old and New LWS

A limited test series was conducted in the old LWS with the prototype DMB operating staged to obtain an approximate indication of its potential for low

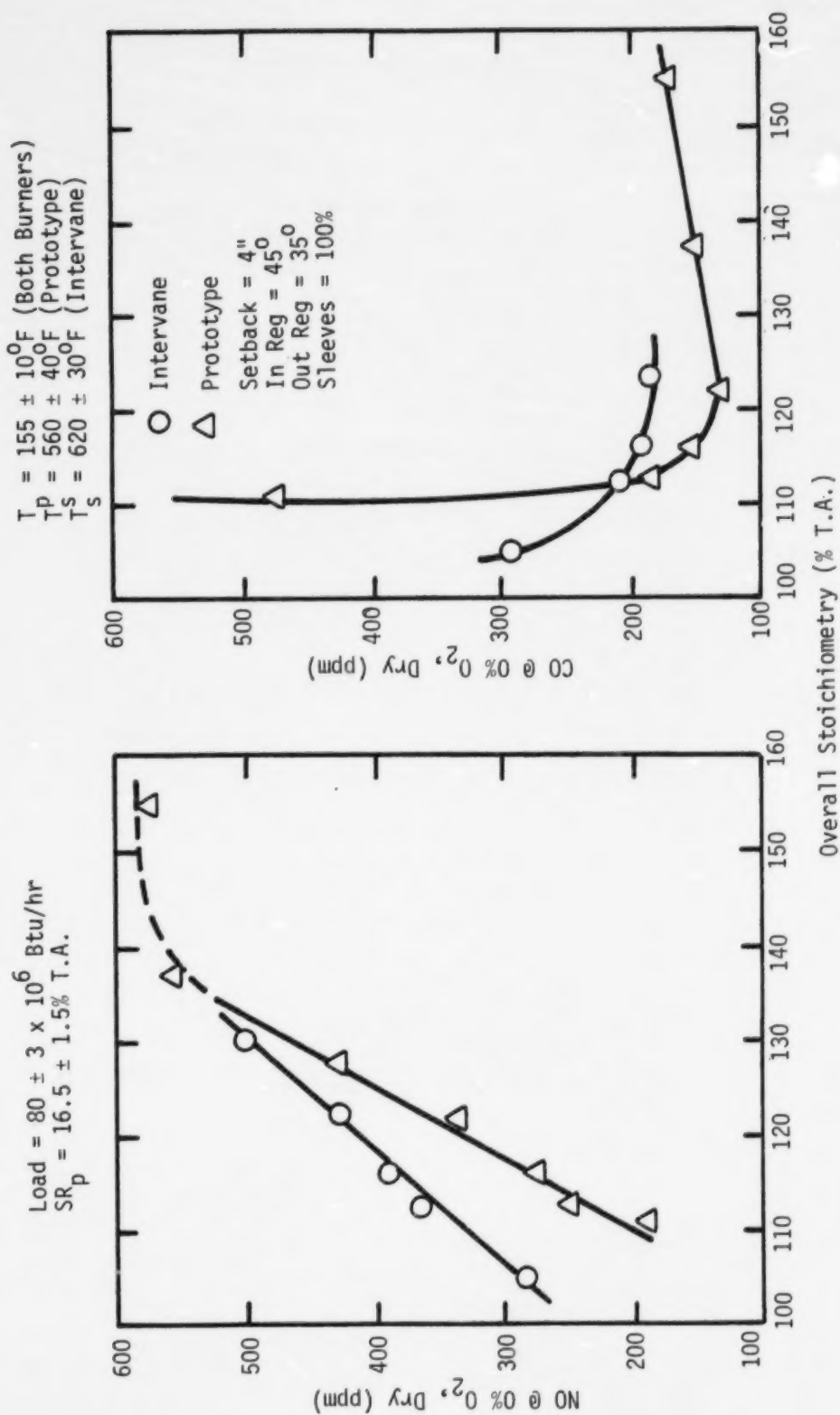


Figure 2-25. Effect of Overall Stoichiometry at Full Load

NO emissions. These tests were preliminary and were halted when the LWS furnace walls deteriorated. Consequently, no attempt was made to optimize burner adjustments and the burner was not operated at the design point. The results in Figure 2-26 show the same decrease in NO as burner zone stoichiometry decreases as that observed in tests of other DMB designs. Extrapolation to the DMB design point (overall stoichiometry 118 percent theoretical air and burner zone stoichiometry 70 percent theoretical air) results in approximately 100 ppm NO. CO emissions increased to unacceptable levels as burner zone stoichiometry decreased. This is probably due to the cold LWS furnace as well as non-optimum burner configuration and adjustment. Optimization of burner adjustments and of burner geometry should result in the characteristic knee observed in the development DMB tests.

The LWS has been rebuilt and additional prototype burner tests have been conducted. The design of the new LWS and comparisons with the old LWS are discussed in the Appendix. The most significant difference in furnace designs is the thermal environment. The new LWS is partially lined with refractory to increase the heat release per unit cooled surface area to the range of field operating boilers.

The objectives of these tests in the new LWS were to compare the prototype burner's performance in the new LWS with the previous test data in the old LWS (to evaluate the effects of the change in thermal environment) and to further evaluate prototype burner performance under staged conditions. The prototype burner was installed in the new LWS and tested at the same conditions and burner settings as the previous tests (except for the nozzle which was set at zero). The new small pulverizer was used for tests over the range of 40 to 70 x 10⁶ Btu/hr and the larger pulverizer was used for tests at high loads. Coal fineness measurements with the Utah coal were 75 and 83 percent through 200 mesh for the small and large pulverizers respectively.

The burner was tested unstaged with only leakage airflow (about 9-10 percent theoretical air) passing through the tertiary ports. The flame shape was comparable to the shape in the old LWS under similar test conditions. The standoff distance was approximately 8-12 inches and the flame length was about 12 feet. Flame stability was unaffected by load over the range 40-100 x 10⁶ Btu/hr. The actual stability range may be greater since no attempt was made to operate outside this range. The unstaged NO and CO emissions at full load are shown in Figure 2-27. The NO emissions were slightly lower than the trend of the data in

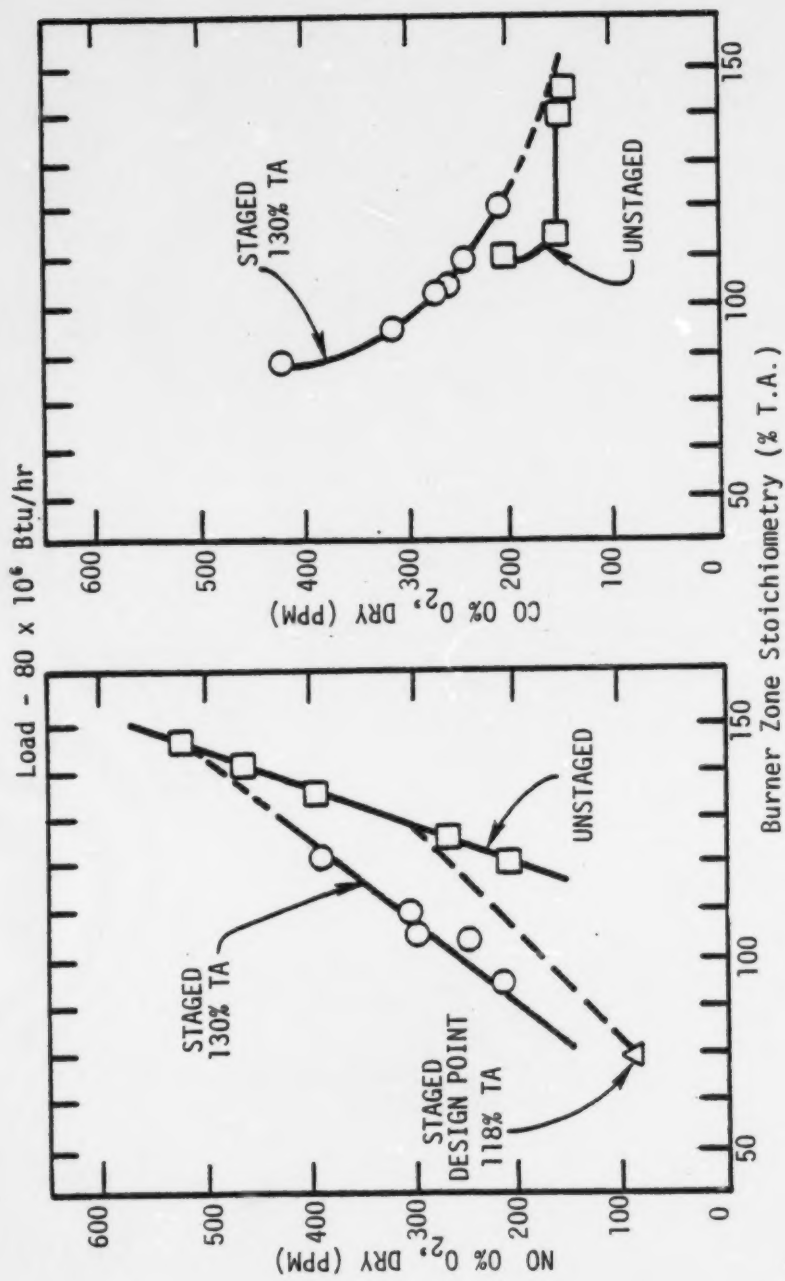


Figure 2-26. Prototype Burner Performance in LWS (Staged):

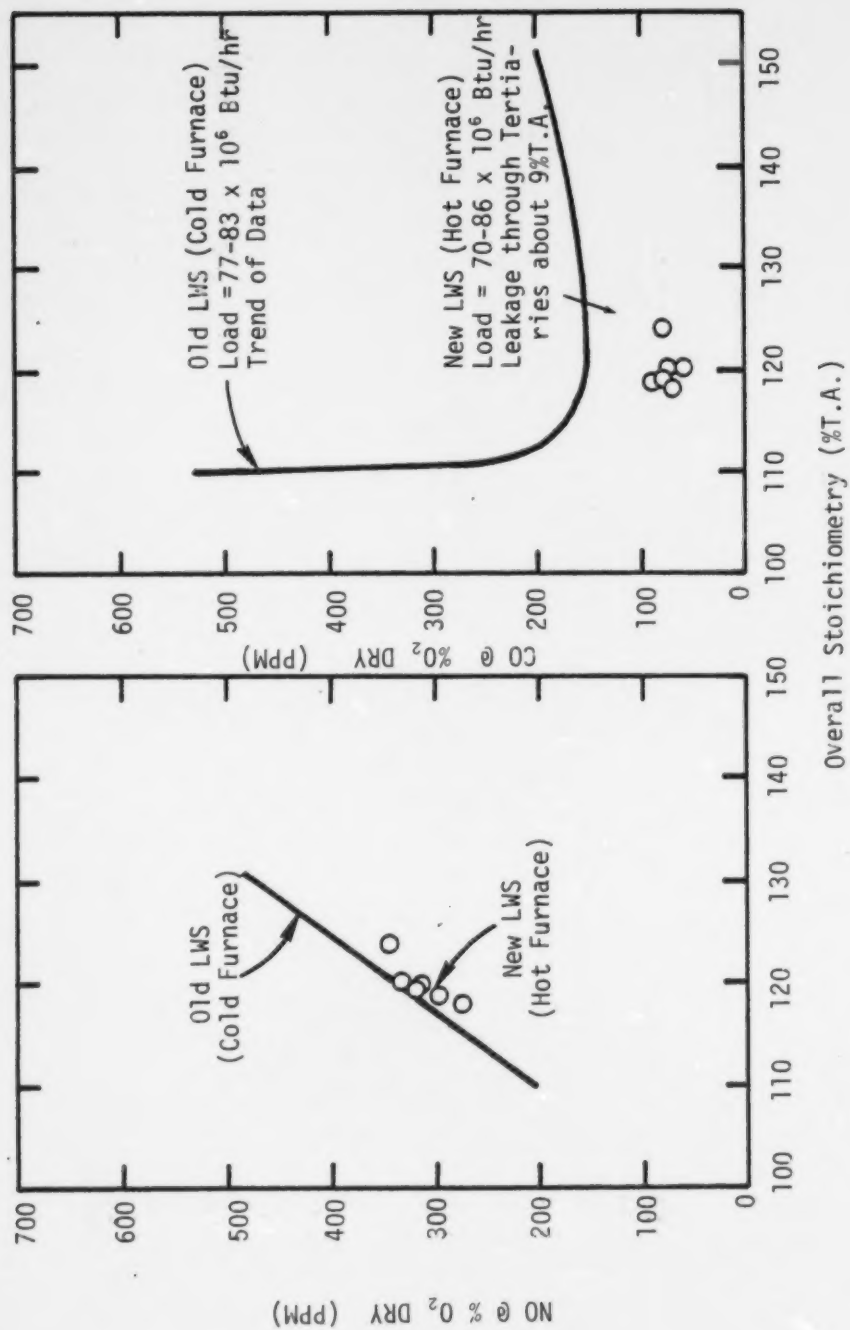


Figure 2-27. Comparison of Unstaged Prototype Burner Performance in Old and New LWS.

the old LWS. Considering data scatter and experimental error, there was no change in NO emissions. However, CO emissions were much lower in the new LWS. At the unstaged design point (118 percent theoretical air) CO was about 75 ppm compared with 150 ppm in the old LWS.

The burner was also tested staged. The NO and CO results are shown in Figure 2-28. Note that the overall stoichiometry was approximately at the design point and lower than the stoichiometry for the tests in the old LWS. Extrapolating the old LWS data to the design point overall stoichiometry yields the dotted line in Figure 2-28. Thus the staged NO emissions in the old and new LWS were comparable. As with the unstaged data, the CO emissions from the staged tests were considerably lower in the new LWS. The CO emissions were within the same range as the unstaged data (less than 100 ppm) which is comparable to field data from commercial burners. At the lowest burner zone stoichiometry CO was slightly higher. This condition (burner zone stoichiometry 85 percent theoretical air) was the stability limit. At lower burner zone stoichiometry the flame lifted off the burner and CO emissions increased sharply. Alternate burner settings were tested in an attempt to achieve stable operations at lower burner zone stoichiometry. Increasing the swirl had a negligible effect on emissions and stability. Retracting the nozzle (decreasing primary velocity) slightly reduced CO emissions and appeared to increase flame stability. However additional testing is necessary to confirm the results.

The stability limit for the prototype burner (85 percent theoretical air) is considerably higher than for the development DMBs (less than 50-70 percent theoretical air). Data suggests that this is due to the differences in nozzle and exit designs. The prototype burner nozzle is annular, while axial nozzles with spreaders were used on the development DMBs. The prototype burner exit lengths were considerably shorter than the development DMBs due to limited windbox depth at the initial demonstration site.

During subsequent tests, the burner design parameters will be modified to increase stability. The following changes will be tested:

- Primary Velocity - The improved stability at lower primary velocity will be confirmed.
- Secondary/Throat Velocity - The throat diameter will be decreased to increase the secondary velocity. This will increase the momentum available to provide a swirl stabilized recirculation zone.

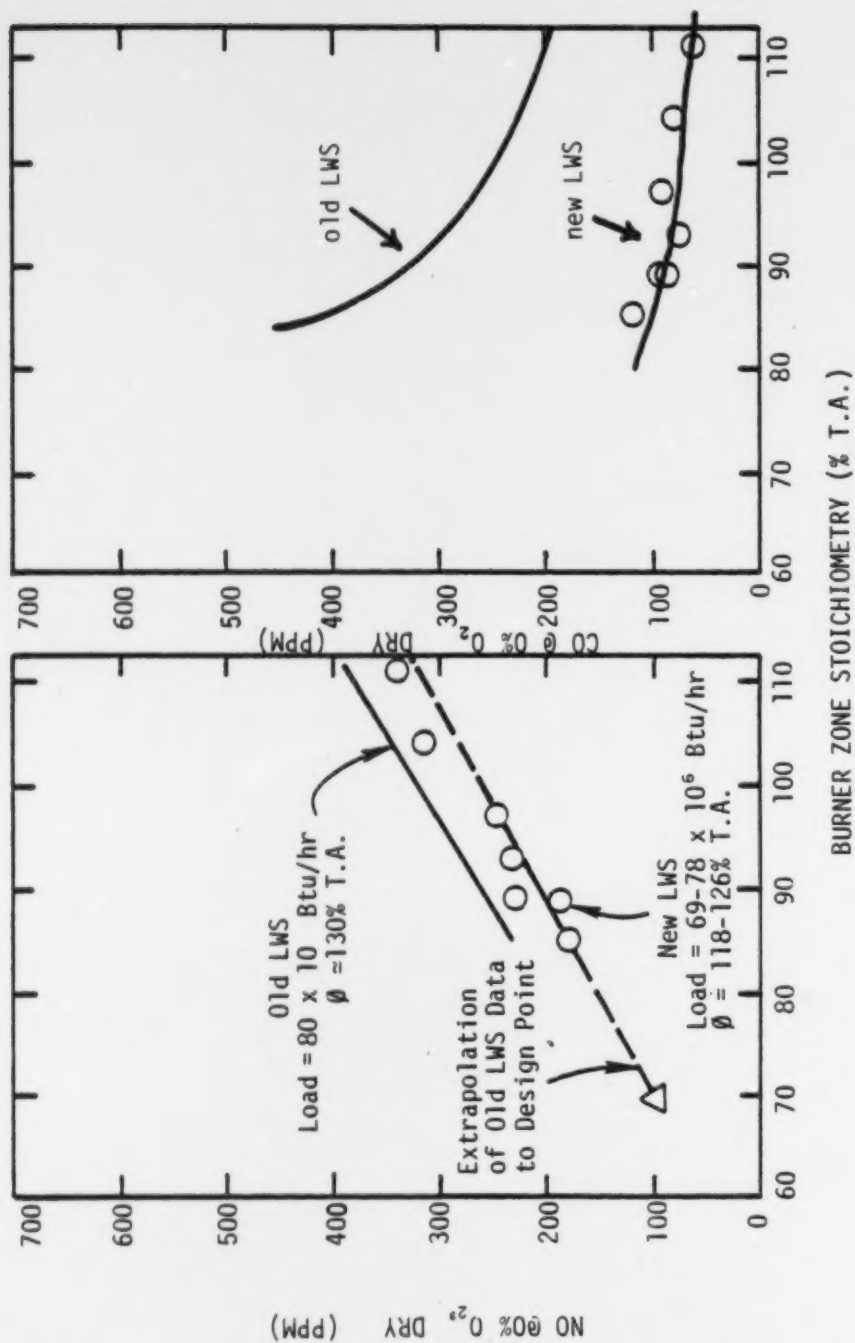


Figure 2-28. Comparison of Staged Prototype Burner Performance in Old and New LWS.

- Nozzle Setback - The nozzle setback will be increased from the current 4.0 inch setting. Increasing the setback from 0.0 to 4.0 inches produced a noticeable increase in stability during previous data.

In summary, the prototype burner performance in the new LWS was similar to the previous tests in the old LWS, except for the CO emissions which were much lower in the new LWS and comparable to field levels. This confirms that the high CO emissions measured with pre-NSPS burners and DMBs in the old LWS were related to furnace, rather than burner, design. There was essentially no increase in NO emissions even though the new LWS furnace is considerably "hotter" than the old design.

2.4 Estimate of Emissions from Field Demonstrations

Foster Wheeler has found that when two burners are tested in a research facility the ratio of NO_x emissions measured in the test facility will be comparable to the ratio of NO_x emissions when the identical burners are operated in field boilers. Thus, the ratio of NO_x emissions for the Intervane Burner and the prototype burner tested in the research furnace should be approximately the same as the ratio of NO_x emissions from the same burners operated in the host boiler. The results of the Intervane Burner tests in the old LWS were discussed in detail in the previous annual report and are summarized in Section 4.4. At 118 percent theoretical air, NO emissions were 440 ppm. The baseline boiler tests are discussed in Section 4 and the NO emissions at full load and 118 percent theoretical air are 829 ppm. The table below summarizes these results and presents an estimate of emissions from the DMB operating in the host boiler at the full load design point.

	<u>Research Furnace</u>		<u>Field Burner</u>	
	NO (PPM)	BASIS	NO (PPM)	BASIS
Intervane	440	Measured	829	Typical Field
Prototype DMB	100	Extrapolation of test results to design point	150-250	Rough Estimate

The 150 to 250 ppm NO range corresponds to approximately 0.18 to 0.30 lb/10⁶ Btu which is in the range of the program objective (0.2 lb/10⁶ Btu).

The difference in thermal environment in the old and new LWS provides additional insight into the potential performance of the DMB in a field operating boiler. Foster Wheeler and Babcock and Wilcox have found that the NO_x emissions from their commercial firing equipment can be correlated with the heat release per unit cooled surface area in the lower portion of the furnace (see Appendix). Figure 2-29 shows the NO_x emissions from the prototype burner tests in the old and new LWS plotted on the Foster Wheeler BZLR correlations. Note that the BZLR for the new LWS is slightly less than the initial field boiler (WIPCO). The line drawn through the prototype DMB data has the same shape as the correlations for the Intervane Burner and suggests that the NO_x emissions from the field evaluation will be slightly higher than the prototype burner test results. Of course, this correlation does not account for the differences in the furnace geometry and flame-to-flame interactions in the field evaluation boiler. Thus, the estimate derived from the prototype tests in the old LWS (150-250 ppm) still appears to be reasonable.

As discussed earlier, the prototype DMB tests involve no optimization of either burner geometry or adjustments and resulted in unacceptably high CO levels at the design operating point. Therefore, the "rough estimate" prediction given above is achievable only if modification and optimization of the burner can reduce CO levels in the field boiler typical to those attainable with the steam generator's original equipment Intervane Burners (less than 50 ppm).

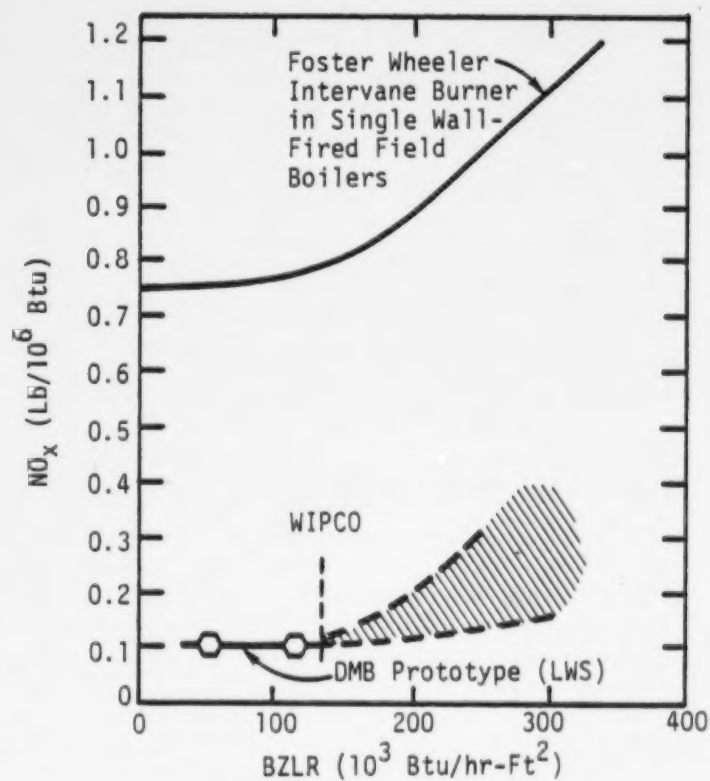


Figure 2-29. Prototype Burner Tests in the Old and New LWS: Comparison with Foster Wheeler NO_x Correlation.

3.0 MEASUREMENTS PROTOCOL

The measurements made during this field evaluation program will quantify the reductions in NO_x emissions achieved by the EPA low emissions coal burner and will identify any potential problems in the application of this technology to field-operating boilers. The accuracy, completeness and appropriateness of the measurements are, thus, key to the program's success. A Measurements Protocol (or measurements plan) has been prepared to ensure that the program goals are achieved: i.e., the evaluation of the EPA low emission coal burner technology on field-operating boilers. Specifically, it identifies the parameters to be measured, measurement methods, calibration procedures, measurement frequency and data quality control/assurance procedures. This Measurements Protocol has been structured so that the following will be achieved:

- Prevent Omission. Many of these tests to be conducted during these programs are costly and cannot be repeated at a later date due to subsequent hardware modifications. The Measurements Protocol specifies those measurements which are necessary to meet specific test objectives, as well as the overall program goals.
- Avoid Unnecessary Measurements. Many of the measurement methods which will be used in this programs are costly and time-consuming. However, a complete assessment of burner/boiler performance is only required for a small number of tests. The Measurements Protocol utilizes a phase approach where the completeness of the measurements is varied according to specific test objectives. For preliminary tests, a simplified measurement format is employed to provide the necessary data at minimum cost. For key tests a complete battery of measurements are performed to fully document performance.
- Appropriate Measurements. The EPA has supported several measurement and assessment programs for stationary combustion sources. The results of these studies and the policies and procedures of the EPA/IERL Process Measurements Branch have been incorporated into this Protocol. In addition, the measurement methods and procedures commonly used in the burner/boiler industry are specified where appropriate. Certification of continuous emission monitors will be performed as a part of field site quality assurance audit.

- Standard Procedures. This program involves evaluations on two field operating boilers. The Measurements Protocol specifies the same measurements and procedures for similar tests on all the field evaluations. Thus, the test results will be directly comparable.
- Data Base. The Measurements Protocol has been prepared recognizing that the data will be used to establish a data base on DMB performance. The measurement formats have been structured so that the results can be used directly by environmental planners as well as burner/boiler designers and operators.
- Data Acceptability. The ultimate objective of this program is to transfer the EPA low emission burner technology to the existing and projected utility boiler population. Thus, it is essential that the measurements taken in the various tasks are of sufficient quality that the information generated leaves no doubt as to the applicability of low NO_x coal burner technology. The Measurements Protocol includes quality control/assurance procedures based on EPA guidelines for field evaluation programs.

The measurements approach as described by The Measurements Protocol specifies the measurements to be performed in Task 2 - Prototype Construction and Testing; Task 3 - Boiler Baseline Evaluation; Task 4 - Burner Installation (referring to checkout testing); and Task 5 - Performance Evaluation. The parameters to be measured and measurement methods are summarized in the following subsection. The design of the measurement system for the initial field evaluation site is discussed in the subsequent subsection.

3.1 Measurements Summary

The Measurements in these programs will be associated with burner tests in the research furnace at EER (LWS) and the field boilers. The burner tests in the LWS will be developmental. Prototype low emission burners will be tested over the operating ranges of the field boilers and the design parameters will be adjusted to produce an optimum balance of flame stability, efficiency and emissions. Commercial burners similar to the original equipment burners on the field boilers will also be tested to establish a baseline. The Measurements Protocol for the LWS tests has been structured to include measure-

ment of key test conditions and test outputs with accuracy and repeatability sufficient to allow the relationship between burner adjustments and burner performance to be determined.

The burner tests in the field-operating boilers will constitute the actual field evaluations of the EPA low emissions burner concept. The initial tests will involve the original equipment and will establish the baseline burner/boiler performance. The low emission burners will then be installed and tested for 18 months. The test results will be used as an index of the performance of the low emission burners in field-operating boilers and will be inputs to air quality plans. The Measurements Protocol for the field tests has been structured to provide more detailed and complete measurement methods and, where possible, all measurements are referenced to absolute or NBS standards.

Figure 3-1 shows the overall organization of the Measurements Protocol. The measurements have been organized into the following categories of increasing complexity:

- Standard Measurement Format
- Detailed Measurement Format
- Effluent Stream Analysis

In addition, corrosion measurements will be conducted as part of the field tests.

The Standard Measurement Format is the minimum set of measurements and will be applied to all LWS and field tests. It includes measurement of the test inputs necessary to specify operating conditions, as well as routine measurement of output parameters. Table 3-1 and Table 3-2 list the parameters and measurement methods for the LWS and field tests, respectively. Where practical, continuous measurement methods have been selected so that the duration of specific tests will be limited by the dynamics of the burner/furnace systems rather than the maximum data acquisition rate. For example, gas phase species in the combustion products will be measured with continuous gas analyzers. During the LWS tests and field tests where burner performance is to be evaluated at specific test conditions, the entire Standard Measurement Format will be applied. The field tests also include intensive 30-day test periods with the original equipment and low emission burners, as well as 18-month, long-term tests of the low emission burners. The Standard Measurement Format will be

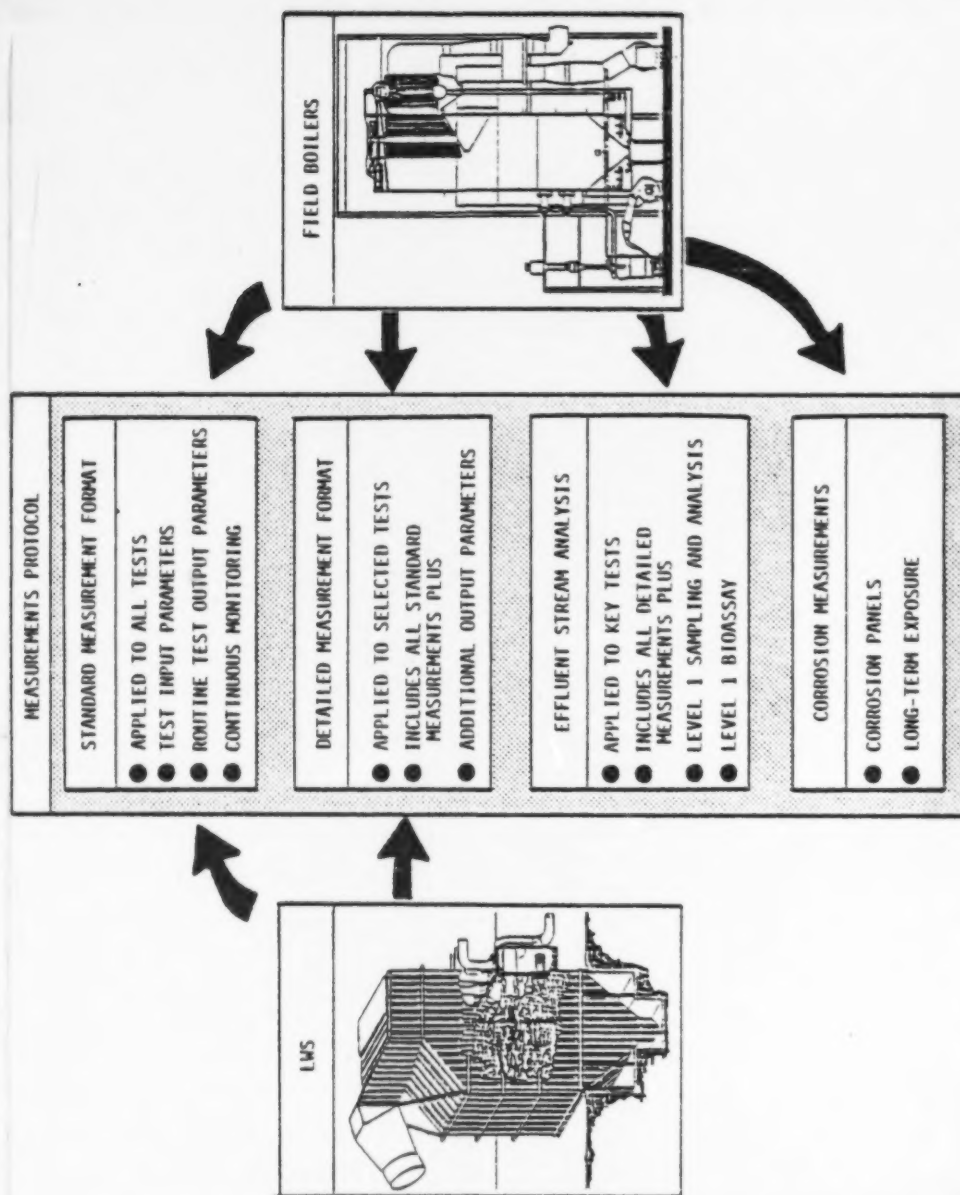


Figure 3-1. Measurements Protocol Organization.

Table 3-1. Standard Measurement Format Summary (LWS).

Test Conditions		Test Outputs	
Parameter	Measurement Method	Parameter	Measurement Method
Furnace Design	Direct Measurement	Flame Characteristics	Direct Observation and/or Color Video
Burner Design		Length	
Burner Adjustments		Width	
Registers		Standoff	
Dampers		Stability	Flame Scanner
Others	Obtain Sample (analyze under detailed format)	Gas Phase Species	Continuous Analyzers
Fuel		O ₂	
Composition		NO/NO _x	
Flow Rate		CO	
		CO ₂	
Combustion Air	Weigh belt feeder or calculate from airflow and excess O ₂	Other	
Flow Rate	Venturis	Smoke	Direct Observation
Temperature	Thermocouples	Windbox Pressure	Pressure Gauge
Distribution	Venturis or Internal Flowmeters	Burner Temperatures	Thermocouples

Table 3-2. Standard Measurement Format Summary (Field).

Test Conditions		Test Outputs	
Parameters	Measurement Method	Parameter	Measurement Method
Furnace Design	Direct Measurement	Flame Characteristics	Direct Observation and/or Color Video
Burner Design		Length	
Burner Adjustments		Width	
Registers		Standoff	
Dampers		Stability	Flame Scanner
Others		Gas Phase Species	Continuous Analyzers
Fuel		O ₂	
Composition	Obtain Sample (analyze under detailed format)	NO/NO _x	
Flow Rate	Boiler Instrumentation	CO	
Combustion Air		CO ₂	
		Other	
Flow Rate	Boiler Instrumentation	Thermal Performance	Boiler Instrumentation
Temperature	Boiler Instrumentation	Smoke	Direct Observation
Distribution	Internal Flowmeters or Boiler Instrumentation	Windbox Pressure	Boiler Instrumentation
		Burner Temperatures	Thermocouples

applied continuously during the 30-day tests and a portion of the Standard Measurement Format (O_2 , CO and NO_x measurement) will be applied continuously during the long-term tests.

The Detailed Measurement Format includes all of the measurements in the Standard Measurement Format plus intermittent measurement of certain output parameters. Table 3-3 and Table 3-4 list the parameters and measurement methods for the LWS and field tests respectively. The Detailed Measurement Format will be applied to selected test conditions to more fully characterize burner performance. During the LWS tests, the Detailed Measurement Format will be applied to the original equipment burner tests and the tests of the optimized low emission burner. The test conditions will be selected to cover the range of operation of the field boilers so that complete maps of burner performance will be obtained. During the field tests, the Detailed Measurement Format will be applied in the same manner to map burner/boiler performance. It will also be applied during the 30-day tests to obtain an index of performance variability. The Detailed Measurement Format includes manual measurements of several parameters, including particulate mass, particulate size distribution and SO_3 . These measurements are time-consuming and may limit the rate of testing.

The Effluent Stream Analysis is the most complex measurement format and will be applied to a few test conditions of special significance. The measurements include an EPA Level 1 Environmental Assessment including Bioassay, as well as certain other emission measurements. Figure 3-2 shows the basic level 1 sampling and analysis scheme for solids, liquids and slurries. As a minimum, the Effluent Stream Analysis will be applied to the full-load operating conditions of the original equipment burners and low emissions burners at each field evaluation site.

Corrosion measurements will be made to ensure that the low emission burners do not contribute to furnace wall corrosion. These measurements will be conducted only in the field boilers since the duration of the LWS tests is too short to accurately assess corrosion rates. Corrosion panels will be installed prior to the low emission burner installations so that data can be obtained with the original equipment burners. Figure 3-3 illustrates the design and installation of the corrosion panels on the initial field evaluation boiler. During the low emission burner installation, the tube thickness will be

Table 3-3. Detailed Measurement Format Summary (LWS).

Test Conditions		Test Outputs	
Parameter	Measurement Method	Parameter	Measurement Method
Fuel		Particulates	
Composition	ASTM Methods (ultimate and proximate) EER Laboratory Methods (ultimate)	Total Mass	EPA Method 5
Size Distribution	ASME Method	Composition	EER Laboratory Methods (ultimate)
		Size Distribution	Andersen Cascade Impactor
		Carbon Balance	Standard Measurement Format
		CO, CO ₂	Hot F.I.D.
		Hydrocarbons	Same as Above
		Particulate	Grab Sample and EER Laboratory Ultimate Analysis
		Bottom Ash	Same as at Left
		Coal	Continuous Monitor and/or EPA Method 6
		Sulfur Balance	EPA Method 8 and Controlled Condensation
		SO ₂	Same as Above
		SO ₃	Same as Above
		Particulate	Same as at Left
		Bottom Ash	
		Coal	

Table 3-4. Detailed Measurement Format Summary (Field).

Test Conditions		Test Outputs	
Parameter	Measurement Method	Parameter	Measurement Method
Fuel		Particulates	
Composition	ASTM Methods (ultimate and proximate)	Total Mass	EPA Method 5
	EER Laboratory Methods (ultimate)	Composition	EER Laboratory Methods (ultimate)
Size Distribution	ASME Method	Size Distribution	Andersen Cascade Impactor
		Carbon Balance	
		CO, CO ₂	Standard Measurement Format
		Hydrocarbons	Hot F.I.D.
		Particulate	Same as Above
		Bottom Ash	Grab Sample and EER Laboratory Ultimate Analysis
		Coal	Same as at Left
		Sulfur Balance	
		SO ₂	Continuous Monitor and/or EPA Method 6
		SO ₃	EPA Method 8 and Controlled Condensation
		Particulate	Same as Above
		Bottom Ash	Same as Above
		Coal	Same as at Left
		Thermal Balance	ASME Method
		Gas Concentrations in the Furnace	Continuous Monitors

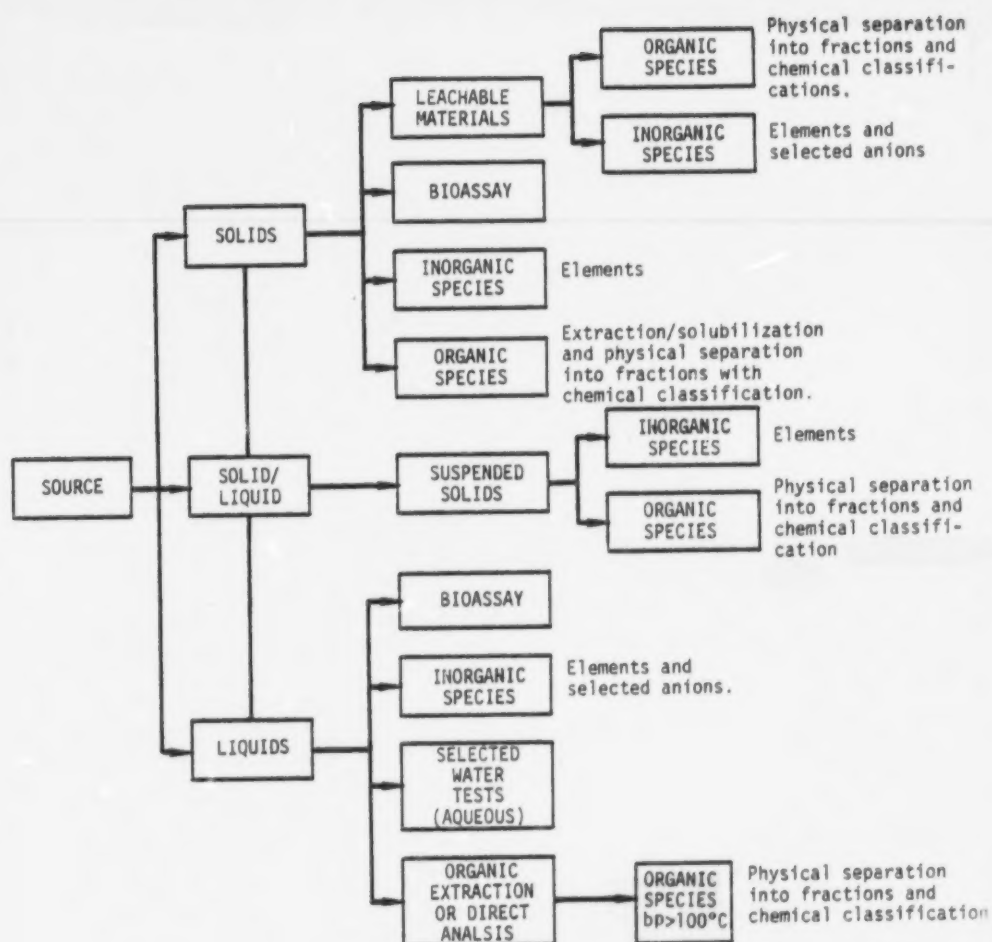


Figure 3-2. Basic Level 1 Sampling and Analytical Scheme for Solids, Slurries and Liquids.

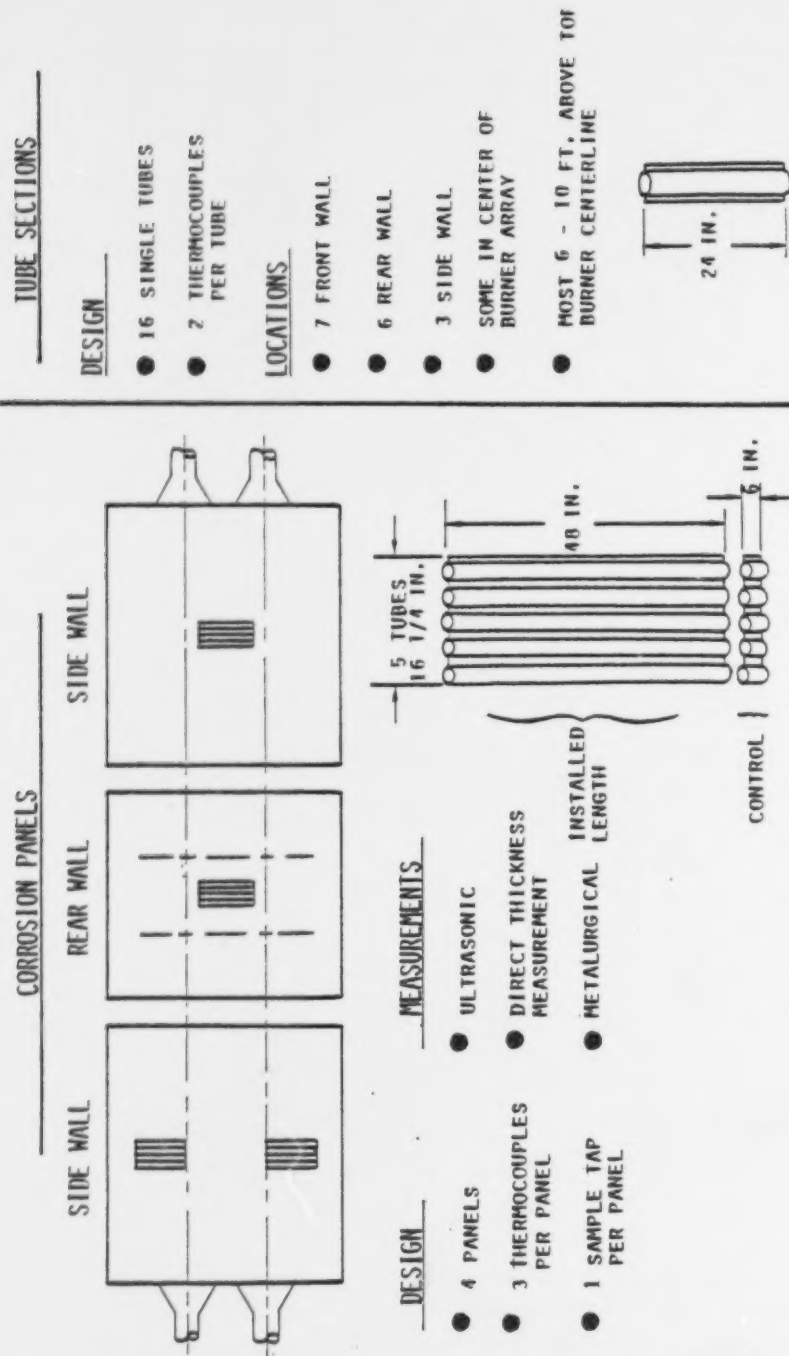


Figure 3-3. Corrosion Panel Installation on the Initial Field Evaluation Boiler.

measured to establish the baseline corrosion rates. At the end of the long-term tests of the low emissions burners, the tube thicknesses will remeasured. This will provide a direct comparison of the corrosion rates for the two burners.

During the LWS tests, data quality will be maintained by following the test procedures in the protocol. However, the increased importance of the field tests requires a Quality Control Plan. To ensure that the emission measurements are accurate, EPA methods will be used as the primary measurement methods or as reference methods. In addition, the continuous monitoring system will be constructed, calibrated, verified and operated according to EPA Performance Specifications 2 and 3. The field tests will also be subjected to a quality assurance audit by an independent EPA contractor.

The Measurements Protocol is intended to be a "working" document. It is recognized that in programs of four years duration there are likely to be advances in the state-of-the art, and throughout the programs the protocol will be updated and revised as necessary. These revisions will come about because of data generated in the proposed program and from data obtained from other sources such as environmental impact studies and relevant development programs.

3.2 Measurement System At The Initial Field Evaluation Boiler

A complete measurement system capable of conducting all measurements required by the Standard and Detailed Measurement Formats has been constructed. It has been installed at the initial field boiler and used to conduct the baseline tests described in Section 4. This section describes the design of the continuous monitoring system and the quality assurance procedures conducted prior to the baseline tests.

3.2.1 Continuous Monitoring System

The measurement system includes continuous gas analyzers for measurement of NO/NO_x, CO, CO₂, O₂, hydrocarbons and SO₂. Table 3-5 lists the instruments and the nominal full-scale ranges which were used during the baseline tests. These instruments are the same as those in service on the LWS except for the NO_x and SO₂ analyzers. The TECO NO_x analyzer is preferred over the Beckman (which is currently in use on the LWS) because of its lower sensitivity to background gas composition variations. This is due to the low pressure reaction chamber used

Table 3-5. Continuous Gas Analysis Instruments.

Gas Measured	Type of Instrument	Manufacturer	Model No.	Full-Scale Range
NO, NO _x	Chemiluminescent	Thermo Electron Corp. (TECO)	10 AR	1000 ppm
CO	Nondispersive Infrared (NDIR)	Anarad, Inc.	AR500R	500 ppm
CO ₂	Nondispersive Infrared (NDIR)	Anarad, Inc.	AR500R	25%
O ₂	Paramagnetic	Taylor Servomex	Type OA 272	10%
H _x C _y	Flame Ionization	Beckman Instruments, Inc.	402	50 ppm (C ₃ H ₈)
SO ₂ ⁽¹⁾	UV Absorption	DuPont	400	5000 ppm
SO ₂ ⁽²⁾	Pulsed Fluorescence	Thermo Electron Corp. (TECO)	40	5000 ppm

(1) Preferred Instrument

(2) Alternate Instrument

on the TECO. The DuPont SO₂ analyzer is preferred over the TECO (which is currently in use on the LWS) because of its greater flexibility and potentially greater accuracy in measuring SO₂ in the presence of active SO₂ sorbent. During the initial field tests, the TECO SO₂ analyzer will be used and the DuPont SO₂ analyzer will be evaluated as part of the EPA Contract 68-02-2667 investigation into sulfur measurement methods. If limestone injection is field tested, the current results of this investigation will be used to upgrade the measurement system.

The instrument ranges listed in Table 3-5 have been selected to exceed the maximum gas concentrations which are expected to be measured by a small margin. Each instrument is calibrated by three gases: a zero gas and two span gases at approximately 50 and 90 percent of span. Table 3-6 lists the span gases for each instrument. As part of the quality control plan, the calibration gases are prepared according to a rigorous EPA Protocol. This involves traceability to NBS certified standards. In cases where the appropriate NBS standards are not available, Gas Manufacturer's Primary Standard (GMPS) grade mixtures will be used. These mixtures are prepared gravimetrically and are the most accurate grade of gas mixtures commonly available. Table 3-6 lists the grades of gases currently available for each span gas.

Sampling Location. Flue gas is sampled immediately upstream of the air heater. This ensures that: 1) the flue gas sample is representative of the boiler effluent, 2) that the sample is not biased by the buildup and intermittent discharge of ash from the air preheater, and 3) the results do not reflect the performance of the emission control system. An array of sampling probes is used. This ensures that the composite sample is representative of the total boiler exhaust. The probes can be sampled separately to assess the variations in gas concentrations across the duct.

The sampling port arrangement for the WIPCO field evaluation boiler is shown in Figure 3-4. Three ports are used for a 3 x 4 array of probes for the continuous monitoring system. Two additional ports are used for manual sampling and can be used for the Level 1 SASS probe. Note that this sampling location does not meet the requirements of EPA Method 1 which specifies a minimum straight length of 2.0 duct diameters upstream and 0.5 duct diameters downstream from the sampling point. However, this is the best location available.

Table 3-6. Calibration Gases.

Gas	Concentration	Percent Full-Scale	Gas	Grade
NO	500 ppm	50	Nitrogen	EPA Protocol
NO	900 ppm	90	Nitrogen	EPA Protocol
SO ₂	2500 ppm	50	Air	EPA Protocol
SO ₂	4500 ppm	90	Air	Gravimetric (GMPS)
CO	250 ppm	50	Nitrogen	EPA Protocol
CO	450 ppm	90	Nitrogen	EPA Protocol
CO ₂	12.5%	50	Nitrogen	EPA Protocol
CO ₂	22.5%	90	Nitrogen	EPA Protocol
O ₂	5%	50	Nitrogen	EPA Protocol
O ₂	9%	90	Nitrogen	EPA Protocol
C ₃ H ₈	25 ppm	50	Nitrogen	Gravimetric (GMPS)
C ₃ H ₈	45 ppm	90	Nitrogen	Gravimetric (GMPS)

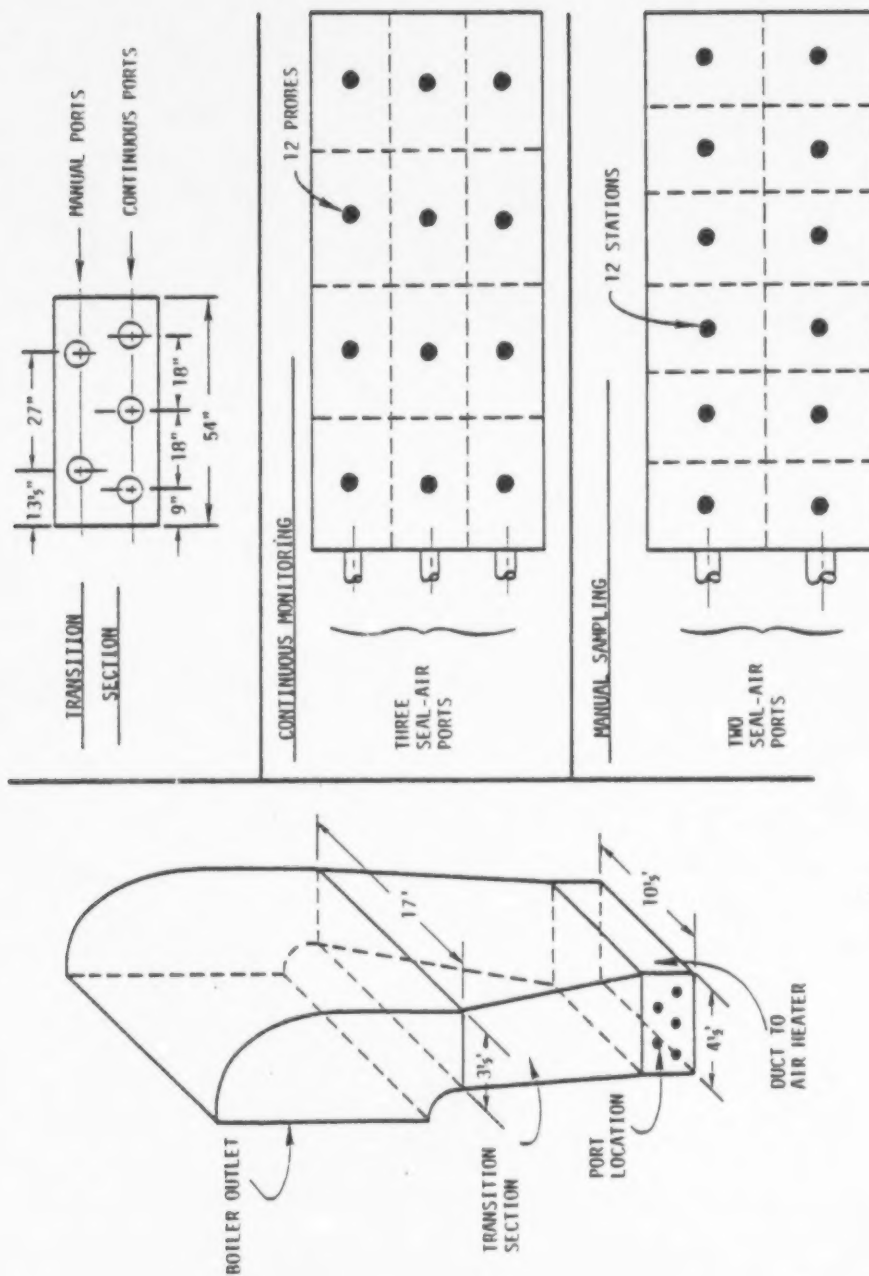


Figure 3-4. Sample Port Arrangement for WIPCO Field Evaluation Boiler.

The duct pressure at the sampling location is approximately 6.0 inches H₂O above ambient. To prevent leakage of combustion products when the ports are opened to traverse or remove probes, each port is equipped with the seal/air system shown in Figure 3-5. During sampling the port opening is sealed and/or the flow rate of compressed air minimized to avoid diluting the sample or altering the flow streamlines in the duct.

Sample Train

Figure 3-6 shows the key elements of the sample train design. All materials in contact with the sample upstream of the reactive gas analyzers (NO_x and SO₂) are limited to glass, stainless steel, Teflon and a small amount of Kel-F. These materials have been shown to have negligible effects on the reactive gases under the conditions present in this sample train. The probes are uncooled stainless steel and are equipped with particulate filters on the tips. These filters are sintered stainless steel cylinders 1.0-inch diameter and 6.0 inches long. The nominal pore size is 0.5 micron. Experience with these filters has been satisfactory and the pressure drop across each filter can be maintained at an acceptable level by daily backflushing.

The sample lines from each probe are heated to maintain the gas temperature above the dew point. These sample lines enter a temperature-controlled box where the sample flow rates in all probes are balanced. The temperature of the box is maintained at about 250°F which is above the moisture dew point. The filters are packed with glass wool. The flow rate through each sample line is monitored and controlled by an orifice, differential pressure indicator and metering valve. A common differential pressure indicator is used for all sample lines. Each orifice is calibrated by measuring the differential pressure at the desired sampling rate. Experience has shown that the orifices (which are cut from Teflon discs) can be produced to have essentially the same calibration. Thus, uniform flow through each probe is indicated by the same differential pressure across each orifice. The temperature-controlled box includes valves to manifold any combination of probes into the single sample line. There is also provision for dry filtered compressed air to back-purge the system.

The sample line exiting the temperature-controlled box is heated to 250°F and conveys the sample to the instruments which are located in a temperature-

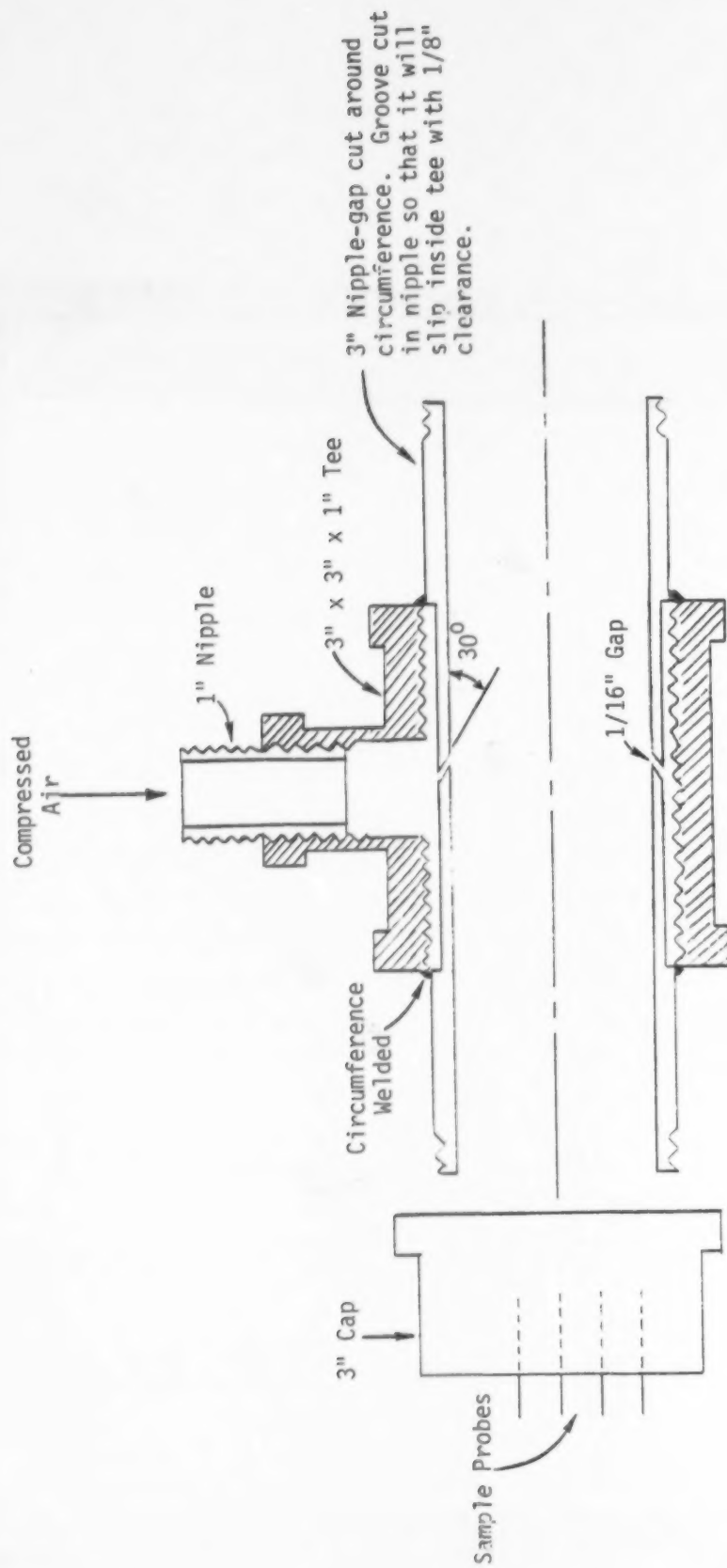


Figure 3-5. Seal Air Sample Port.

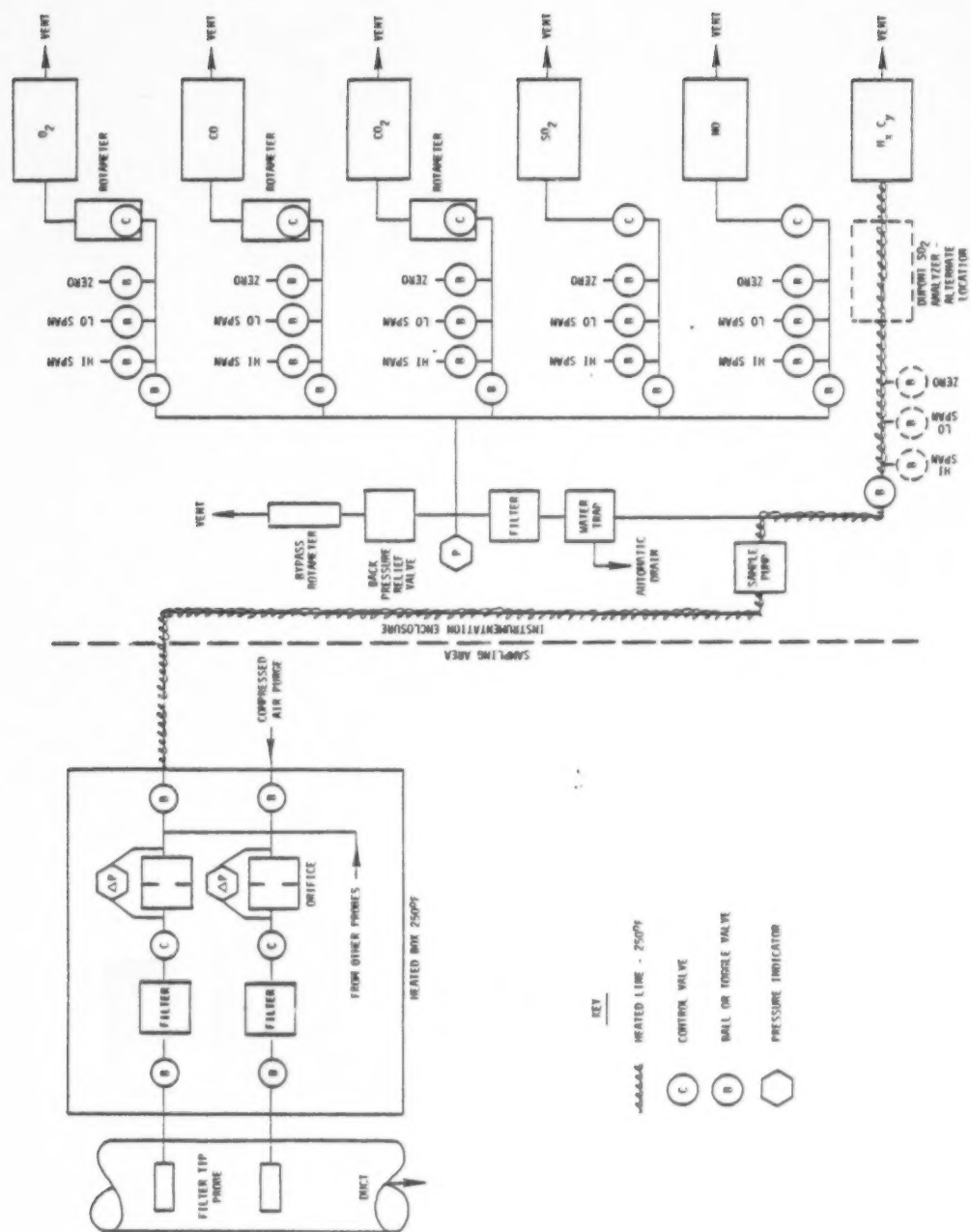


Figure 3-6. Field Sample Train.

controlled environment (air-conditioned trailer). A teflon-lined sample pump provides the pressure and is operated at the maximum possible flow rate to achieve minimum sample line residence time. An insulated sample line goes directly to the hydrocarbon analyzer (and DuPont SO₂ analyzer, if available). The remainder of the sample is dried and filtered and then distributed to the analyzers. Excess sample (which is the majority of the flow rate) is vented through a back pressure relief valve. The sample flow rate is measured by a bypass rotameter and smaller rotameters connected to each instrument. The TECO analyzers (SO₂ and NO_x) have internal flowmeters. The zero and span gas connections are arranged so that each instrument may be spanned separately.

The signals indicating the gas concentrations on each instrument are supplied to a strip-chart recorder. A data acquisition system is also used to facilitate the evaluation of calibration data and for data reduction during the long-term tests.

3.2.2 Quality Control/Assurance

The key element in the Quality Control Plan (which is detailed in the Measurement Protocol) is a verification that the continuous monitoring system conforms to EPA Performance Specifications 2 and 3. This verification was conducted prior to the baseline tests. The Performance Specifications are for NO_x, SO₂, CO₂ and O₂ monitors which are used to demonstrate compliance with New Source Performance Standards. The design of the continuous monitoring system for the field tests meets the construction requirements of the Performance Specifications. The operational specifications are listed in Table 3-7. A zero gas and two span gases are required for each instrument. The span gases are 50 and 90 percent of the span range and must be certified to be accurate. The certification involves either preparation according to EPA Protocol No. 1 (which involves comparison against NBS standards) or a specified calibration procedure involving comparison against EPA Manual methods.

Performance of the monitoring system is verified in a two-week tests. During the first week (conditioning period), the system must operate with no unscheduled maintenance, repairs or adjustments. During the second week (operational period), the system is tested for compliance with the remaining specifications listed in Table 3-7. This includes zero drift, calibration

Table 3-7. EPA Performance Specifications for Continuous Analyzers.

Test	NO _x and SO ₂	O ₂ and CO ₂
Span Gas	EPA Protocol	Same
Conditioning Period	≥168 hours	Same
Operational Period	≥168 hours	Same
Calibration Error	≤5% of each mid-level and high-level calibration value	Same
Response Time	≤15 minutes	Same
Zero Drift (2 hours)	≤2% of span	≤0.4% CO ₂ or O ₂
Zero Drift (24 hours)	≤2% of span	≤0.5% CO ₂ or O ₂
Calibration Drift (2 hours)	≤2% of span	≤0.4% CO ₂ or O ₂
Calibration Drift (24 hours)	≤2% of span	≤0.5% CO ₂ or O ₂
Relative Accuracy	≤20% of the mean value of reference method(s) test data in terms of emission standard or 10 percent of the applicable standard, whichever is greater	Same

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Zero Drift (24 hours)	≤2% of span	≤0.5% CO ₂ or O ₂
Calibration Drift (2 hours)	≤2% of span	≤0.4% CO ₂ or O ₂
Calibration Drift (24 hours)	≤2% of span	≤0.5% CO ₂ or O ₂
Relative Accuracy	≤20% of the mean value of reference method(s) test data in terms of emission standard or 10 percent of the applicable standard, whichever is greater	Same

drift and relative accuracy. In the relative accuracy test, the responses of the continuous monitors are compared with EPA Manual measurements. EPA Method 6 is used for SO₂, EPA Method 7 is used for NO_x and EPA Method 3 is used for CO₂ and O₂.

The EPA Performance Specifications include NO_x, SO₂, O₂ and CO₂ monitors, but do not cover CO and hydrocarbon monitors since these pollutants are not currently regulated by New Source Performance Standards. To provide some assurance that CO and hydrocarbons are monitored accurately, the monitors for these species were tested in the same manner as the others. However, since there are no appropriate EPA Manual methods for these species, the relative accuracy tests were not conducted.

The key element in data quality assurance is a review of test procedures, equipment, documentation, and measurement accuracy by an independent third party. The measurement system at the initial field evaluation boiler was subjected to on-site qualitative systems audits and quantitative performance audits by RTI, an independent auditor selected by EPA.

A system audit provides an assessment of facilities and equipment, adequacy of test procedures selected, conformance to test procedures, maintenance and calibration procedures selected, and documentation. The performance audit assesses the accuracy of data using independent measurement techniques, primarily involving the analysis of reference samples. Table 3-8 summarizes the audit procedures conducted at the initial field boiler. The results of the audit were satisfactory except for some minor problems which have since been corrected. However, the hydrocarbon analyzer was not operational during the period and will be audited at a later date.

Table 3-8. Summary of Test Methods and Audit Procedures

TEST METHOD	SYSTEMS AUDIT PROCEDURE	PERFORMANCE AUDIT PROCEDURE
Continuous Monitoring Instrumentation	Review of facilities and equipment. Review of calibration and maintenance procedures. System documentation.	Analysis of standard compressed gases introduced at sampling probes. Individual probe flow rates checked against NBS.
EPA Reference Methods 2, 3, 4, 5, 6, 7, 8	Observation of sample collection and analysis. Review of data forms, calibration, and documentation. Check of equipment for conformance to EPA specifications.	Method 3: Analysis of standard gases. Method 5: Check of gas meter accuracy against calibration orifice. Methods 6 and 8: Analysis of standard sulfuric acid solutions. Method 7: Analysis of standard NO ₂ samples in absorbing solutions.
Controlled Condensation for SO ₃	Observation of sample collection. Review of data forms, test procedure, equipment, and documentation.	
In-Stack Cascade Impactor for Particle Size	Observation of loading of impactor with substrates, sample collection, and unloading of impactor.	

4.0

BOILER BASELINE EVALUATION

The objectives of the Task 3 Boiler Baseline Evaluation are to measure the performance of the field evaluation boilers over their normal ranges of operation with the original equipment burners and to determine the potential for NO reduction without burner replacement. The results of these tests will be used to quantify the net improvement in performance achieved by the EPA low emission burners. The Boiler Baseline Evaluation is being conducted in four test series as follows:

- Burner Modification Tests
- 30 Day Baseline Tests
- Thermal Efficiency Tests
- Effluent Stream Analysis (Level 1 Tests).

The Burner Modification Tests involve evaluating the boiler performance at specific conditions spanning the full range of operation. The relationships between the operating parameters (load excess air and burner settings) and performance are evaluated. In addition, the potential for NO reduction by off design point operation, burners out of service etc. is determined. These tests were conducted during the summer of 1980. A Foster-Wheeler service engineer was present for the duration of the tests to ensure that the operating conditions were representative of normal burner/boiler performance. EER coordinated the tests and operated the measurements systems described in Section 3. The results of these tests are discussed in this section.

The 30 Day Baseline Test involves monitoring burner/boiler performance continuously over a 30 day period. The boiler load and operating conditions are selected by the boiler operators as determined by steam demand and previous experience. This test was conducted immediately after the Burner Modification Test. Over the 30 day period, the boiler operated at full load for a majority of the time. The emissions were comparable to those measured at full load during the Burner Modification Test. Statistical analysis of these data is will be reported in the third annual report.

The Thermal Efficiency Test includes measurement of the overall thermal efficiency of the boiler, as well as the distribution of heat absorption in the

furnace and convective passes. These tests will be conducted in the spring of 1981 prior to the installation of the low NO_x burners. The Effluent Stream Analysis including a complete EPA Level 1 Environmental Assessment will be conducted at the same time.

4.1 Full Load Operation

The Maximum Continuous Rating (MCR) for the boiler is 20.0 MW. This corresponds to a firing rate of 70×10^6 Btu/hr for each burner. The design point excess air is 18 percent which results in 3.3 percent O_2 in the dry combustion products. The boiler is normally base loaded and operates at this condition for extended periods. The operators normally position the core air valves on each burner at fully open. They adjust the register, as shown in Figure 4-1. At full load, the upper registers are more open than the lower registers. According to the boiler operators, these settings produce the most uniform flame shapes on all four burners. At low loads, all burners are adjusted to produce more swirl than at full load. A Foster Wheeler service engineer inspected the burner settings and flame shapes and determined that they were within the range normally observed on units of this type.

The flames from all four burners stabilized close to the throat exit (within about two inches). This is similar to the flame shape observed during the Intervane Burners Tests in the LWS. The WIPCO furnace was filled with luminous combustion products, and it was difficult to delineate flame boundaries. The flames were definitely shorter than the furnace depth (no rear wall flame impingement). However, they were not symmetrical in the furnace. No flame impingement was observed on the side walls adjacent to burners 1 and 3. The flame from burner 4 was observed to brush or roll along the adjacent side wall. The side wall adjacent to burner 2 could not be observed due to the location of the observation port. Typical full load gas phase measurements from sample taps on the furnace walls and upstream of the air heater are summarized in the table below:

Species	Upstream of Air Heater	Furnace Walls		
		Adjacent to Burners 1 & 3	Adjacent to Burners 2 & 4	Rear Wall
O_2 (%)	3.11	3.35	= 0	2.87
CO (PPMP)	43	286	>500	281
NO_x (PPM)	741	642	405	736

Note: Burner Locations as Viewed from Rear of Windbox.

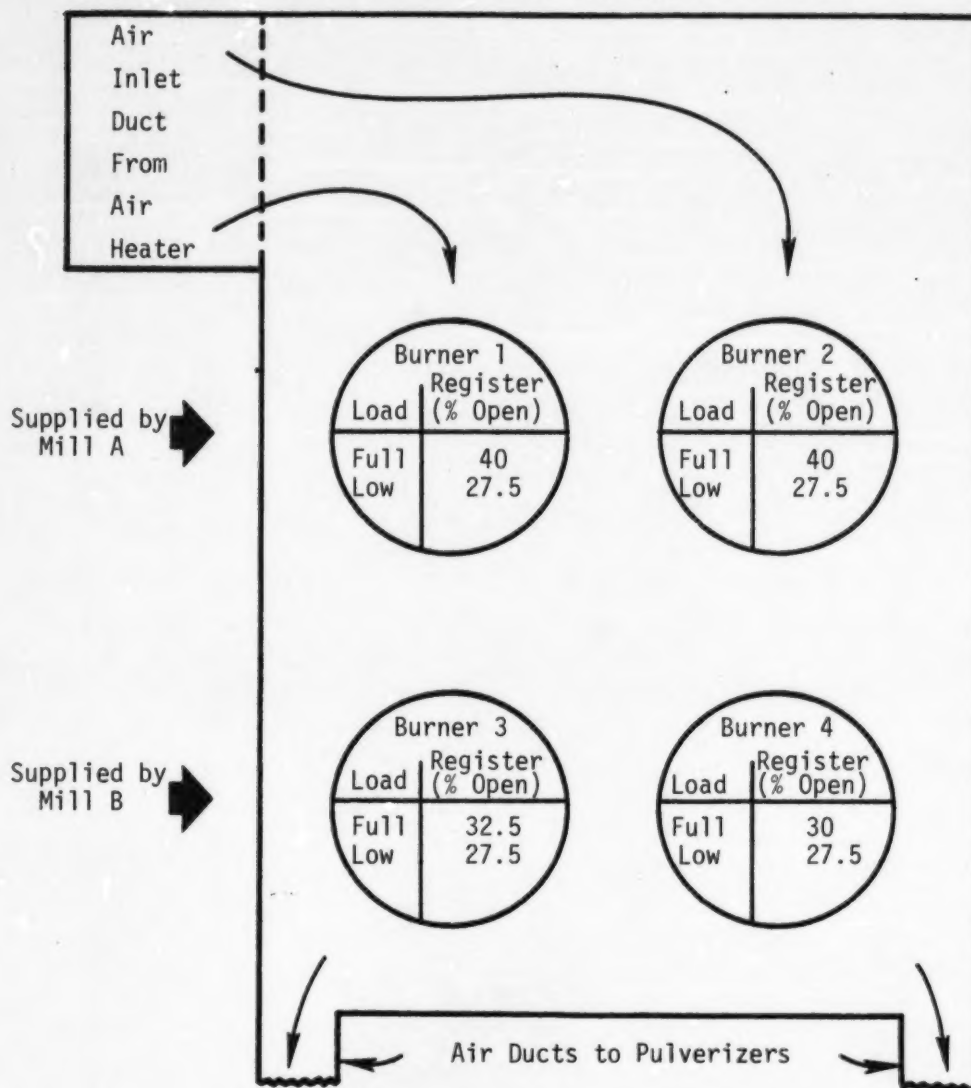


Figure 4-1. Normal Register Adjustment.

These measurements confirm that reducing conditions (zero oxygen and high CO) existed in the areas where the flame was observed to contact the furnace wall. Measurements of the same gases at the twelve probe locations upstream of the air heater resulted in essentially uniform results. Thus, the variations in gas concentrations exiting the burner zone are effectively smoothed out in the upper furnace and/or convective pass. Register adjustments were unsuccessful in producing symmetrical flames. Foster-Wheeler has advised that this condition is unusual and is investigating the problem. One possibility is that the coal from pulverizer B is not distributed equally to burners 3 and 4.

The gas phase concentrations measured upstream of the air heater at the MCR design point were as follows:

Species	Concentration Dry, 0% O ₂
O ₂	3.42% (as measured)
NO	829 ppm
CO	41 ppm
CO ₂	18.0%
SO ₂	2964 ppm
HC	1 ppm

These results are the average of four tests. The O₂ concentration corresponds to 18.7 percent excess air and the load averaged (20.5 MW). These are essentially the design point conditions. Carbon and sulfur balances based on the typical coal analysis result in 18.2 percent CO₂ and 3200 ppm SO₂ for full conversion. Thus the CO₂ and SO₂ concentrations are reasonable. The low CO and HC concentrations are comparable to those observed on other Foster-Wheeler boilers of similar design (CO emissions are typically reported as "less than 50 ppm"). The NO_x emissions are somewhat higher than expected for boilers of this type. Foster-Wheeler had previously estimated 700 ppm (600 ppm @ 3% O₂).

Burner/boiler performance was measured over a range of excess air at full load (MCR). The NO_x results are shown in Figure 4-2. NO_x is observed to decrease with excess O₂ as expected. The minimum excess O₂ (2.5 percent) was specified by the WIPCO management. Based on their experience, the flames may become unstable at lower O₂ levels. However, this was not observed during the

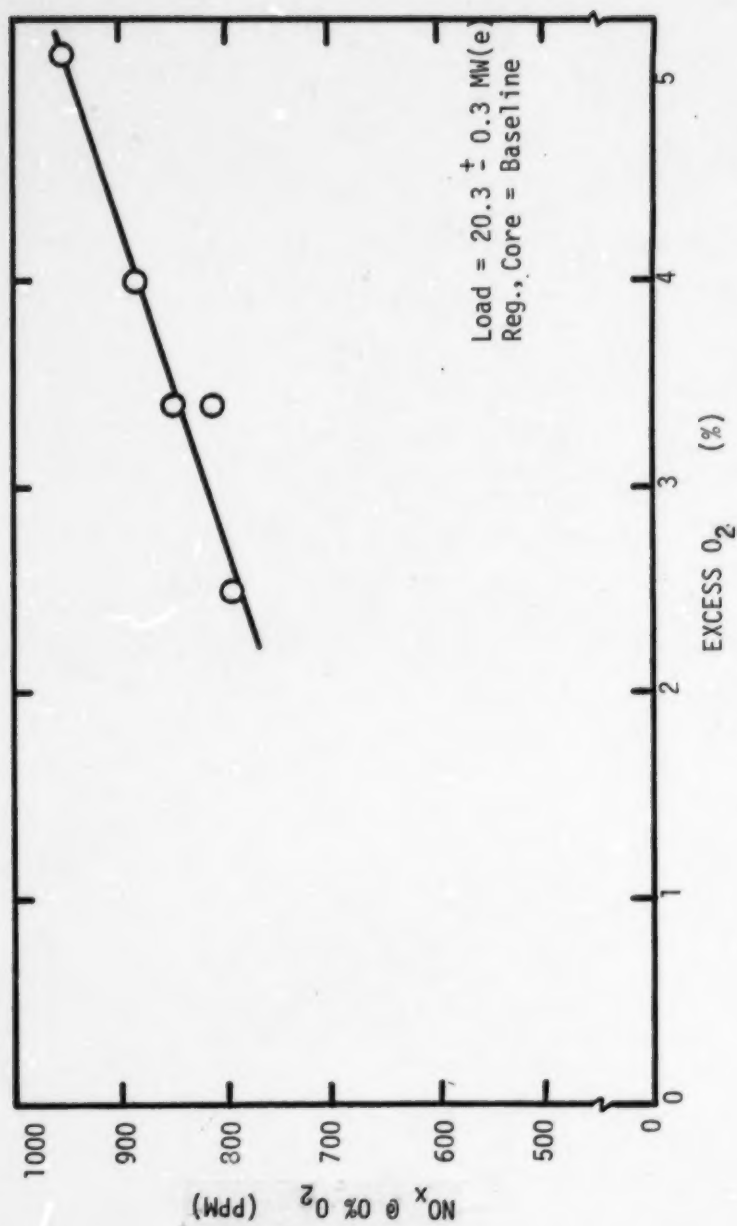


Figure 4-2. Effect of Excess Air Variation at MCR.

current tests. Over the range of excess air, CO and hydrocarbon emissions remained essentially the same as at the design point.

The sensitivity of burner performance to variations in the burner settings (register and core) was evaluated at MCR. The flame stand-off distance was found to be sensitive to register position. Opening the register more than 5 percent from the baseline setting caused the base of the flame to move into the furnace and resulted in a loss-of-flame indication from the scanner. Closing the register more than 5 percent drew the flame back into the throat. The overall flame shape was not influenced by register position. The effect of register position on NO_x is shown in Figure 4-3. There is essentially no change in NO_x emissions due to these small register variations. CO emissions were also unaffected.

Variations in the core air valve setting resulted in a small change in flame shape and a larger change in NO_x emissions than variations in register position. Closing the valve from full open (baseline setting) to 50° drew the flame into the throat approximately 2 inches. The effect on NO_x emissions is shown in Figure 4-4. Closing the valve to 50° increased the NO_x emissions by approximately 100 ppm. This is probably due to increased fuel/air mixing in the throat as evidenced by the retracted flame.

4.2 Low Load Operation

With all four burners in service, the boiler can be operated over a 13 to 21 MW range. The upper end of the range is based on steam side limitations. Previous attempts to exceed 21 mw have resulted in a loss of steam pressure in the accumulator. The lower end of the range is based on flame stability problems which have been encountered at lower loads. The reason for the instability has not been determined. It is expected that the instability may be due to inability of the coal feeders to operate at low feed rates. The feeders are oversized and at loads less than 15 MW, the feed rate has been observed (by the operator) to vary erratically.

The effect of load on NO_x emissions with all burners in service is shown in Figure 4-5. The load curve is quite flat with NO_x decreasing by about 50 ppm as the load is reduced from 100 to 75 percent of MCR. There was no significant

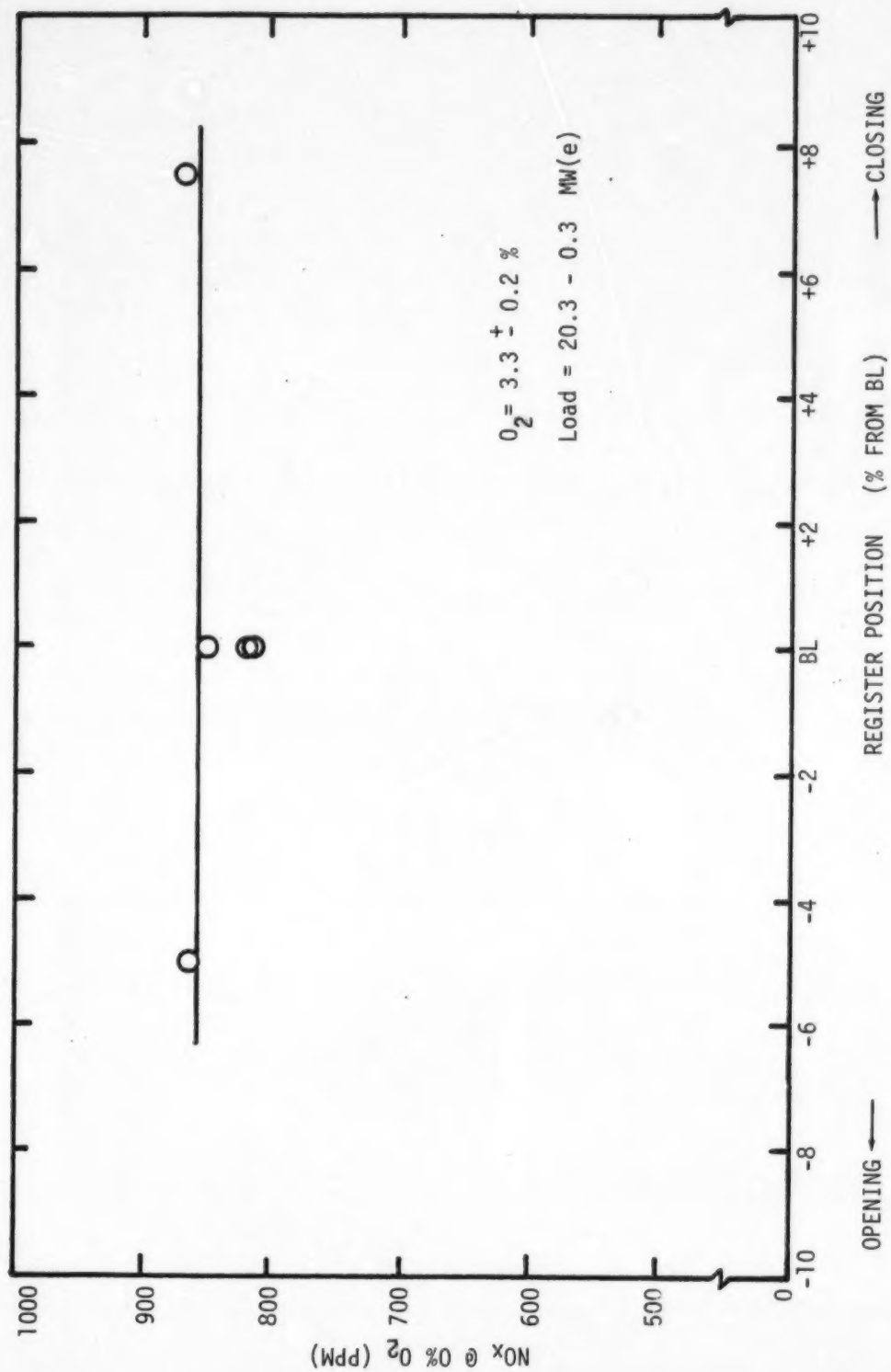


Figure 4-3. Effect of Register Variation at MCR.

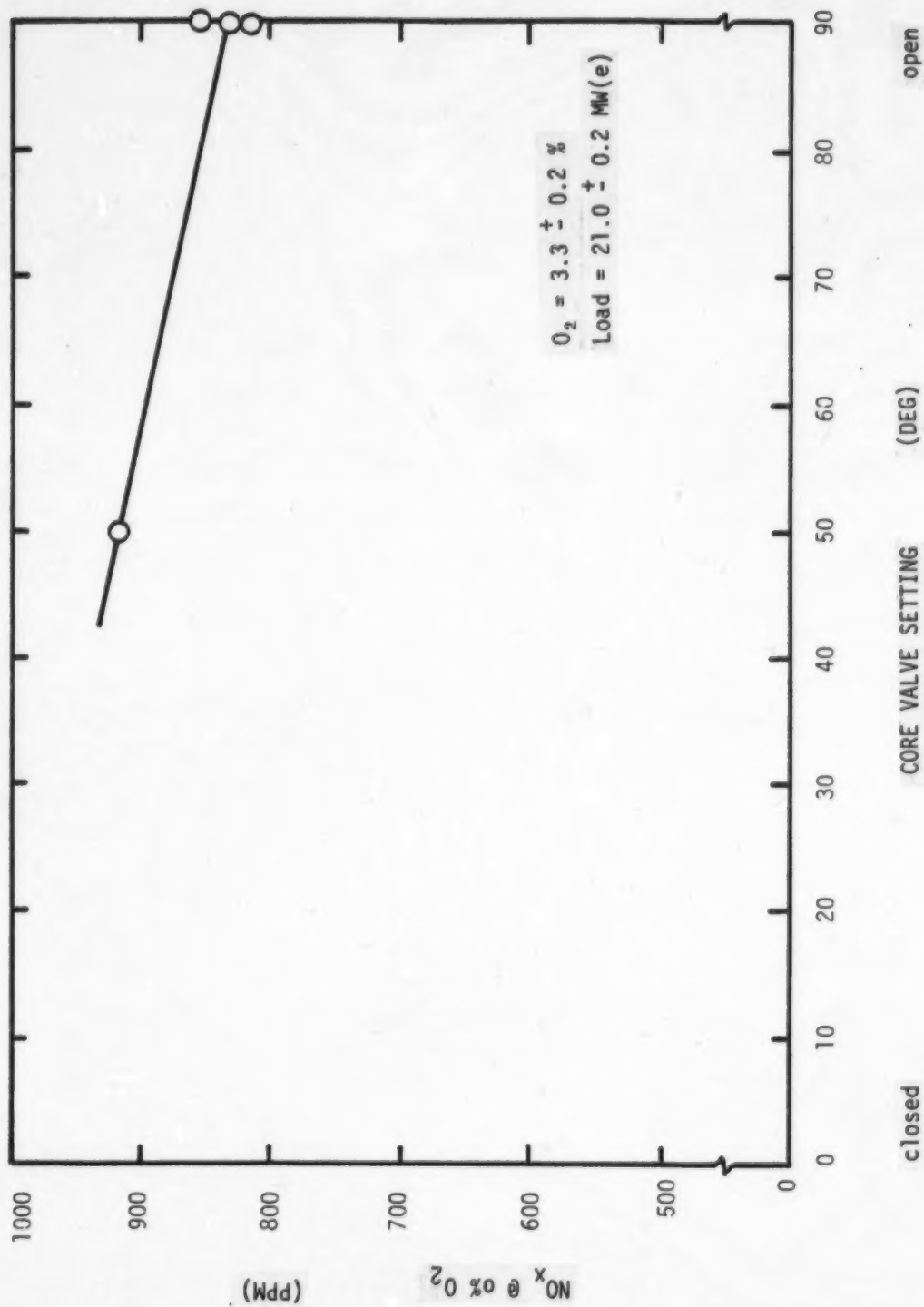


Figure 4-4. Effect Of Core Variation At MCR .

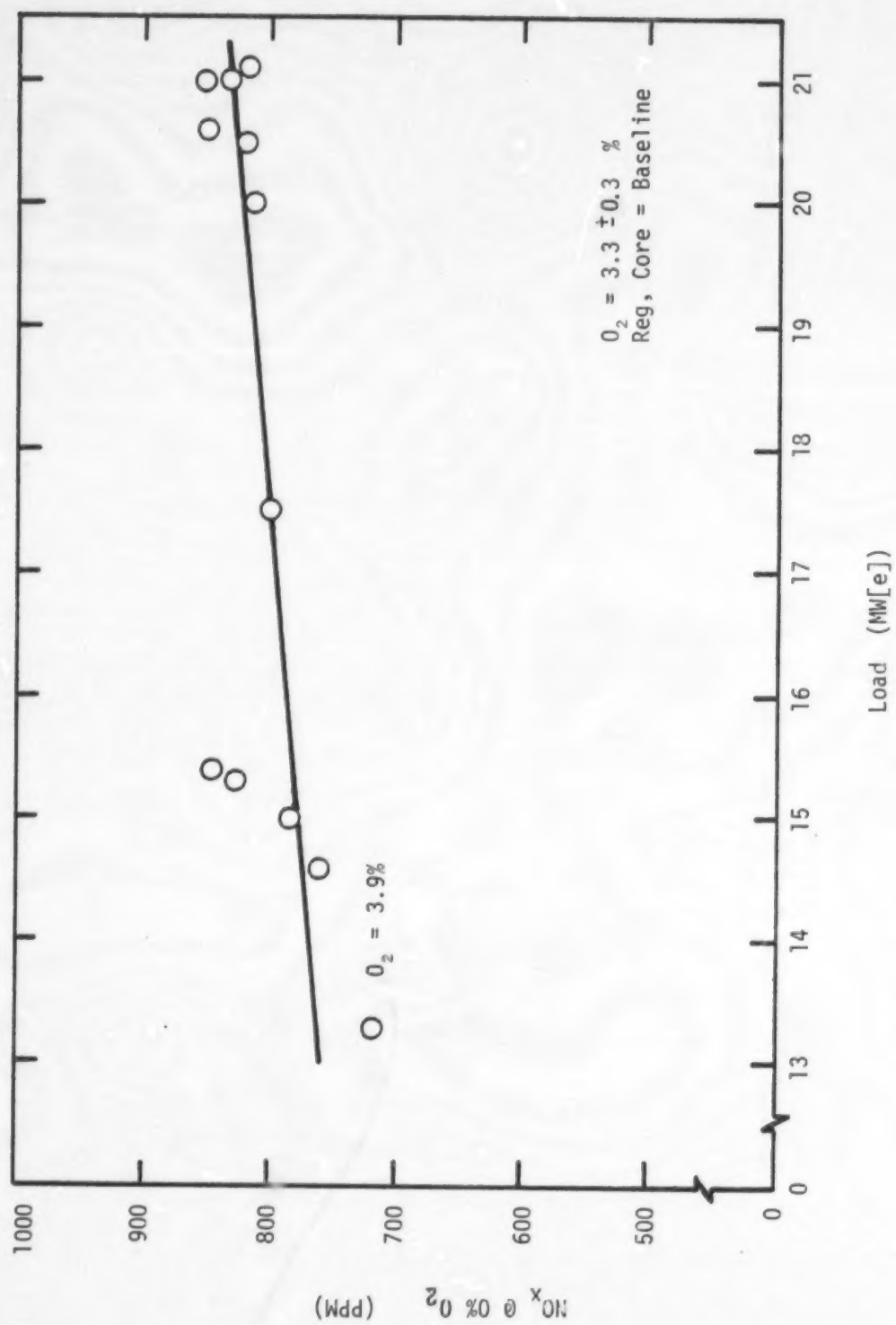


Figure 4-5. Effect of Load.

change in CO or HC emissions over this range. CO and HC emissions were always less than 30 and 3 ppm respectively. Figure 4-6 compares the excess air curves at MCR and 75 percent of MCR. As expected, both curves are essentially straight lines with comparable slopes.

The WIPCO boiler could not be operated with one mill (two burners) in service without supplementary oil firing for flame stability. Attempts to shut off the supplementary oil firing with two burners in service caused the flames to lift off the burners and resulted in a loss-of-flame indication on the flame scanning system. It is possible that the flames stabilized out of range of the scanning system, but this could not be confirmed due to the limited duration of the tests. Foster-Wheeler has advised that this is not typical of normal operation. The burners normally have a 2.5/1 turndown range and operate stably with some burners out of service.

4.3 Low NO_x Operation

The objective of this program is to evaluate and quantify the reductions in NO_x emissions which can be achieved by retrofitting the Distributed Mixing Burners. The reductions in NO_x emissions will be measured from the minimum NO_x emissions which can be achieved without burner replacement or other major modifications. During this test series, low excess air and bias firing were evaluated.

As previously discussed, the minimum excess O₂ level tested was 2.5 percent. At this condition, combustion was satisfactory and the NO_x emissions were reduced to 796 ppm. This is a 4 percent reduction from the baseline (829 ppm). This is an insignificant reduction and may cause slagging during long term operation.

Bias firing involved operating the upper and lower burners at different firing rates and/or excess air levels. This was achieved by varying the coal feed rates to the two pulverizers which supply the upper and lower burners separately. The coal feed rate to the lower burners was increased while the coal feed rate to the upper burners was decreased maintaining the total coal feed rate constant. The net effect was firing a majority of the coal through the lower burners at low excess air while providing additional air through the upper burners to complete combustion. This partial staging tends to reduce

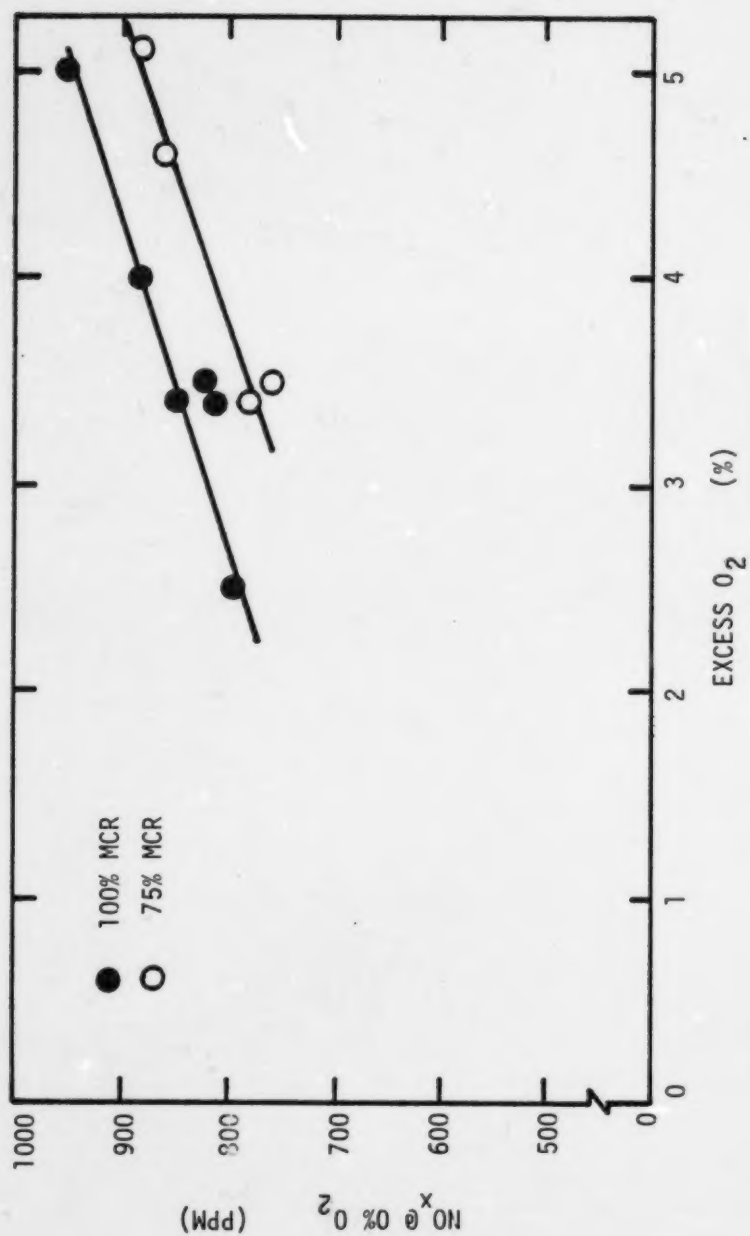


Figure 4-6. Excess Air Variation at 75 and 100% MCR.

NO_x emissions as shown in Figure 4-7. The maximum bias was limited by the minimum feeder speed on the mill supplying the upper burners. The stoichiometry at the lower burners decreased as the bias increased to 95% theoretical air (substoichiometric) at the maximum bias.

As the mill bias was increased, the ignition point of the lower flames was observed to move slightly out of the exit (2-3 inches) and the path of unburned coal and air passing through the exit appeared darker than normal. The flame volume also increased and the flames were observed to roll along both sidewalls. The concentrations of O₂ and CO measured at the sidewalls showed almost no O₂ and very high CO levels. However, the CO in the exhaust remained low even at the maximum bias.

The maximum bias resulted in a 19 percent reduction from the baseline (829 ppm). This is a significant reduction, but sustained operation at this condition would be expected to result in considerable slagging and/or corrosion in the lower portion of the furnace.

4.4 Comparison with Intervane Burners Tests in the LWS

A Foster-Wheeler Intervane Burner similar to those in service at WIPCO was tested in the LWS over a range in excess air and load with the Utah baseline coal. The burner installation and firing system was first checked by a Foster-Wheeler Service Engineer to ensure that it conformed to commercial practice. The field engineer then supervised the burner start-up and adjustment of controls to establish full-load operating point providing acceptable flame shape/length and performance characteristics. At this burner setting, the input coal and airflows were then varied (identical to field operation) over the WIPCO load and excess air ranges.

In general, the burner performance was similar to that observed at WIPCO. The flame was short, bright, intense and stable but somewhat narrower and longer than at WIPCO. The base of the flame was within the cylindrical portion of the exit and filled the divergent portion. In the furnace, the flame expanded rapidly and was about 12 feet (five throat diameters) long. The burner controls (register and core air control valve) affected the flame shape and optimum flame stability was achieved with the register and core at 44 and 87 percent open respectively. These settings are similar to the baseline WIPCO

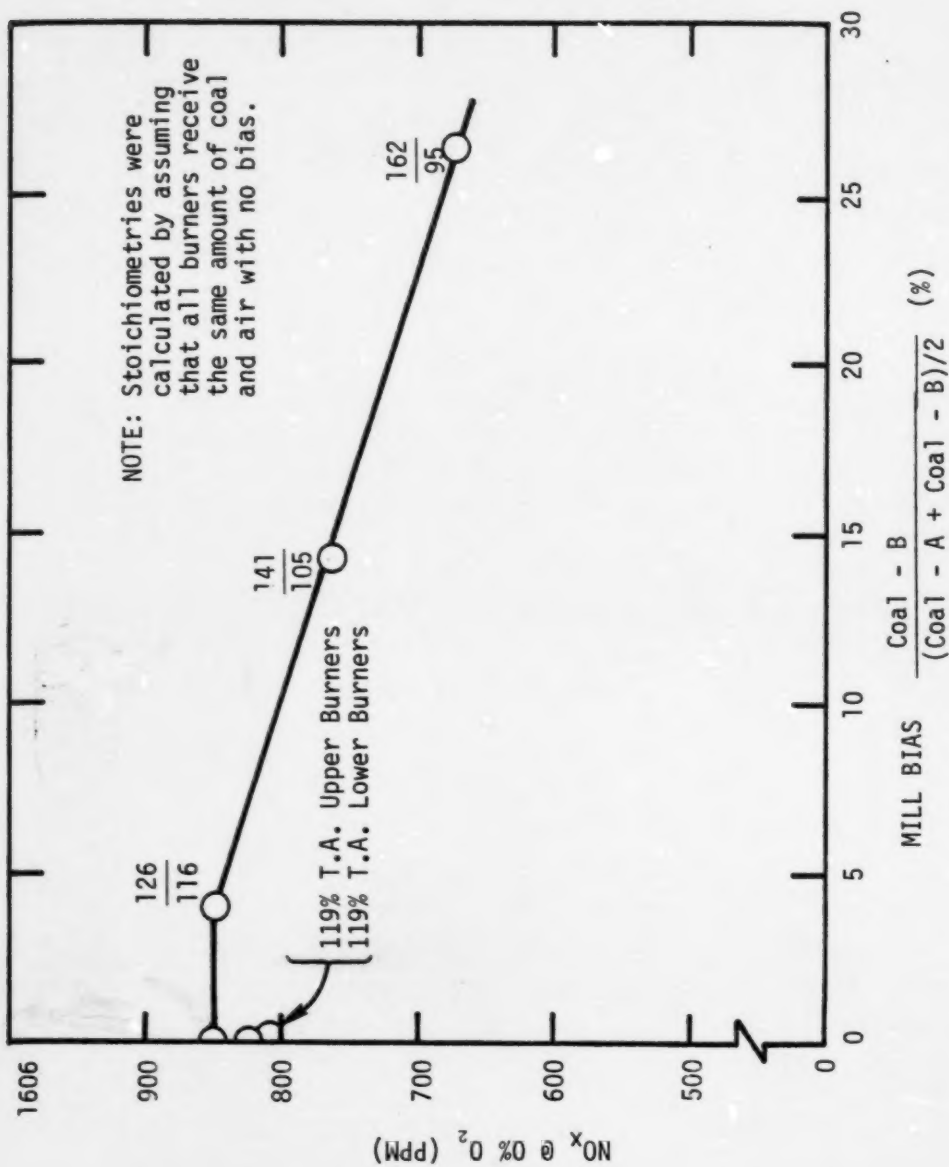


Figure 4-7. Bias Firing.

settings. This similarity between Intervane Burner performance in the LWS and in the field suggests that the DMB flame shape and stability characteristics observed in the LWS tests will be similar in the field.

The NO and CO characteristics for the Intervane Burner tested in the LWS are shown in Figure 4-8. The asymptotic value of CO (at high excess O_2) is about 185 ppm. This compares with less than 50 ppm measured at WIPCO. This suggests that the high CO levels measured during the DMB tests in the LWS may be due to furnace design and/or sampling point location (at the furnace exit) rather than burner performance. This was confirmed by the prototype testing in the new LWS which resulted in substantially lower CO emissions comparable to field measurements (see Section 2.3.2). The increase in CO as excess air is reduced occurs at about 112% TA (2.3% excess O_2) in the LWS. Since the WIPCO tests were limited to greater than 2.5% excess O_2 , there is no way to determine where the knee would occur. However, Foster-Wheeler advises that the knee typically occurs at about 110 percent which is slightly lower than the LWS test result.

The variations in NO_x with excess O_2 and load measured in the LWS and at WIPCO are similar. However, the absolute value of NO emissions in the LWS is considerably lower. Extrapolating the LWS results to full load (90×10^6 Btu/hr) gives an NO_x level of 400 ppm while 829 ppm was measured at WIPCO at the design point excess air (118 percent TA). These data were combined with the prototype burner test results in Section 2.4 to estimate the NO_x emissions which may be achieved by the Distributed Mixing Burner operating in the WIPCO boiler. However, it should be noted that there are some design differences between the Intervane burner installed at WIPCO and the Intervane Burner tested in the LWS. In particular, the WIPCO burner has a nominal capacity of 69×10^6 Btu/hr while the LWS burner has a capacity of 90×10^6 Btu/hr. In addition, the throat configurations are somewhat different. The composition of the baseline Utah coal fired in the LWS is also different from the host coal. These differences may influence the NO_x emissions. The larger burner tested in the LWS would be expected to produce lower NO_x due to the lower throat velocities and less intense fuel/air mixing. An Intervane Burner identical to those at WIPCO will be tested in the LWS with the host coal next year to resolve these questions.

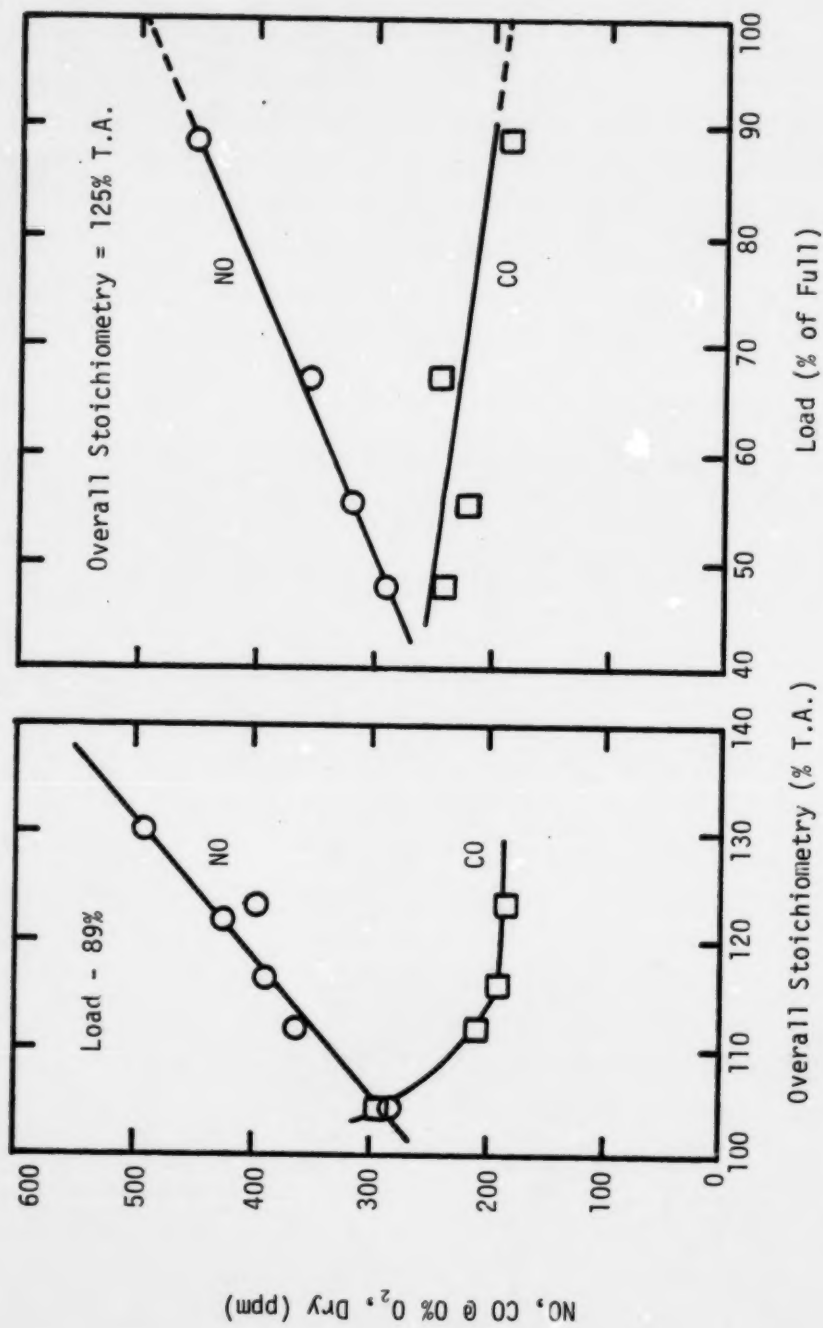


Figure 4-8. Intervane Burner Performance in Research Furnace.

5.0 FUTURE EFFORTS

The schedule for the remainder of the program depends on the schedule for installation of the DMBs in the field evaluation boilers. Both boilers operate continuously except for brief maintenance outages once or twice a year. The outages are scheduled during periods of low power demand (spring and fall) when the utilities are able to purchase replacement power from interconnected power plants. To minimize problems for the field boiler owners/operators, the DMB installations must be conducted during scheduled outages. Considering the overall aspects of the program and the outage schedules, the earliest possible dates for the DMB installations are as follows:

- Initial Field Evaluation (WIPCO) 3/15/81
- Second Field Evaluation 3/15/82

The program schedule based on these dates is shown in Figure 5-1.

5.1 Initial Field Evaluation

As discussed in section 4, most of the Boiler Baseline Evaluation at the initial field evaluation site has already been completed. In March 1981, the Thermal Efficiency Tests and Effluent Steam Analysis (Level 1 tests) will be conducted. All tests will be completed and the data will be evaluated prior to the low NO_x burner installation.

Based on the prototype DMB test results, additional testing in the LWS will be required to identify the burner parameters and settings which optimize performance and to verify burner operation over the required range. Unfortunately, the time available prior to the spring burner installation date will be insufficient to incorporate the test results in the field operable burner design and fabricate four burners. Thus, this approach requires the burner design to be established and fabrication to be started based on current test data. Subsequent prototype burner test results would then be used to verify that the burner design is satisfactory. This is a high risk approach because it is possible that the prototype test results may determine that the burner design must be modified.

An alternate approach would be to incorporate the Foster Wheeler proprietary burner design criteria into the prototype DMB. Burners designed according to

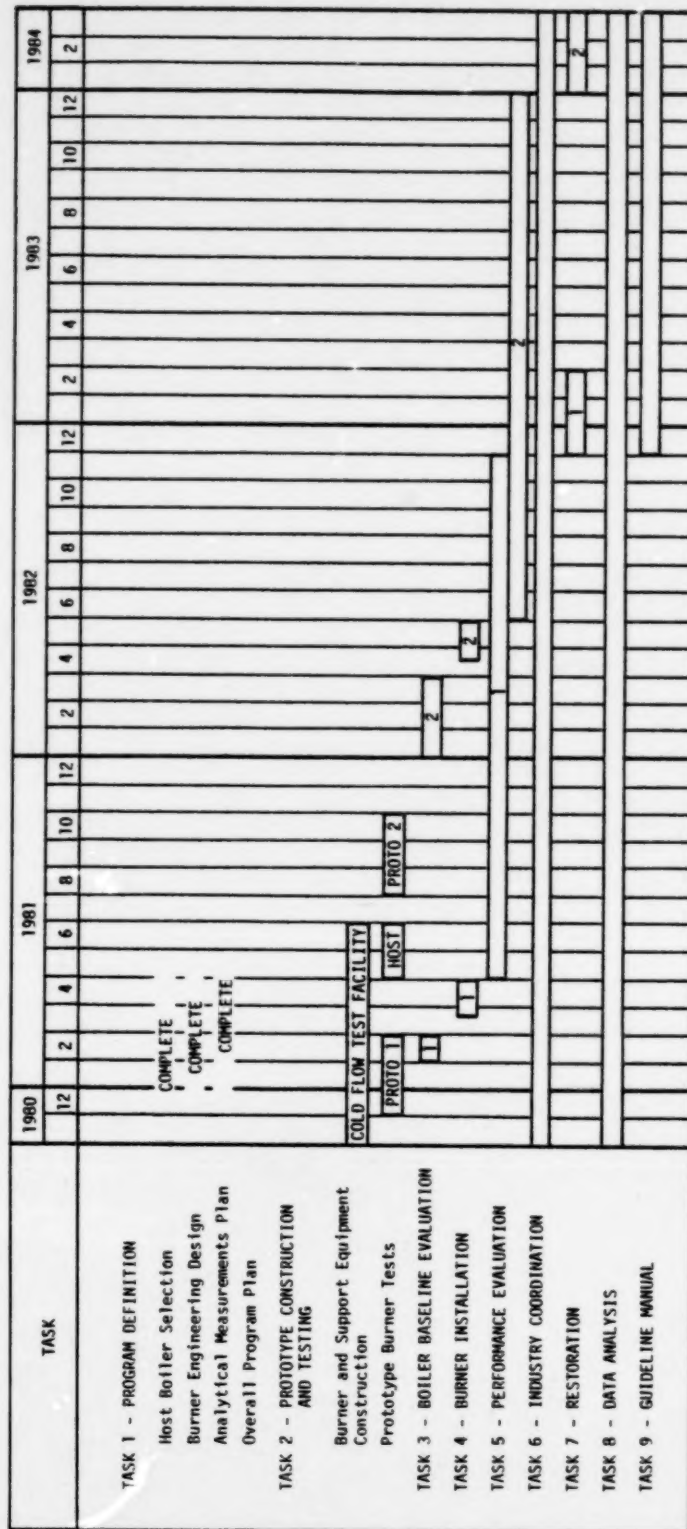


Figure 5-1. Revised Schedule.

these criteria have already been demonstrated to be stable over the required operating range. They could be installed in the field boiler and operated unstaged without additional prototype burner testing. However, satisfactory staged operation would need to be verified. This approach would ensure that the low NO_x burners are installed as early as possible and would maximize the probability of success through the use of proven commercial hardware. Approval to proceed with this approach has been received from the Project Officer.

In January 1981 the prototype burner will be removed from the LWS and modified to meet the new design specifications. This will involve modification of the following burner components.

- Coal Nozzle - The telescoping portion of the coal nozzle will be changed to achieve the specified primary velocity. The nozzle setback will also be changed. However, this can be achieved with the removable nozzle rings built into the current burner design.
- Secondary Divider - The ratio of inner-to-outer secondary areas must be changed. This will involve replacing the steel cylinder which separates the secondary passages in the burner throat.
- Exit - A new exit quarl will be cast.

The burner will then be reinstalled in the LWS for testing with the host site coal. The testing will focus on verifying that the burner will operate stably and with high efficiency (low CO emissions and unburned carbon loss) over the full demonstration boiler operating range. If necessary, the burner parameters will be adjusted to optimize staged performance. However, the installation of the field operational burners will proceed without these modifications. If modifications are necessary for optimum staged performance, the burners will be operated unstaged until a short outage (one week or less) can be scheduled. Assuming that no modifications are necessary, the long-term testing will commence as early as June 1981 and will be completed by November 1982.

5.2 Second Field Evaluation

The second demonstration has been scheduled so that results from the initial demonstration can be evaluated prior to freezing the burner design. The burner design for the second field evaluation will be based on the prototype burner design recently tested in the LWS. As discussed in Section 2, it is expected that some parameters may need to be modified to achieve stable staged

operation at the design point (burner zone stoichiometry 70 percent theoretical air). The prototype burner tests will be completed in the summer of 1981.

The measurement system for the second field evaluation site is now under construction and will be completed and installed on-site during the fall 1981 scheduled outage. The baseline boiler evaluation will be conducted in January 1982.

The low NO_x burners will be installed during the spring 1982 scheduled outage, which will probably occur in April, 1982. The second field evaluation will then be completed in December, 1983.

APPENDIX: NEW LWS TEST FACILITY

The EPA Large Watertube Simulator (LWS) was erected in the fall of 1976 and was used to test the distributed mixing burners under EPA contracts 68-02-1488, 68-02-2667 and 68-02-3127. In January 1980, it was necessary to suspend testing due to corrosion of the furnace walls. The LWS has now been rebuilt and upgraded under EPA contract 68-02-3193. The new LWS was used for the second series of prototype burner tests (described in Section 2) and will also be used for all future burner tests on this program.

The facility will be described in terms of the following systems:

- Furnace
- Cooling
- Fuel Supply
- Air Supply
- Exhaust

Figure A-1 is a schematic diagram of the facility showing the interaction of these components.

Furnace

Table A-1 lists the characteristics of the LWS furnace and Figure A-2 shows the construction details. The overall shape of the furnace is similar to a small pulverized coal-fired industrial or utility boiler. The burner zone has a rectangular plan with a 22-foot firing depth and a 16-foot width. This should contain a 125×10^6 Btu/hr conventional pulverized coal flame without flame impingement. The vertical furnace walls are lined with an insulating refractory up to 16 feet above the knuckle. The remainder of the furnace is uninsulated steel and is externally spray-cooled as discussed below. The hopper is of conventional design with the sloping portions beneath the firing face and target wall. Ash accumulates in the hopper bottom and is periodically removed (once per week). Several viewing ports are located in the vertical side walls for direct flame observation.

In large multiburner boilers, furnace dimensions are based on flame shape

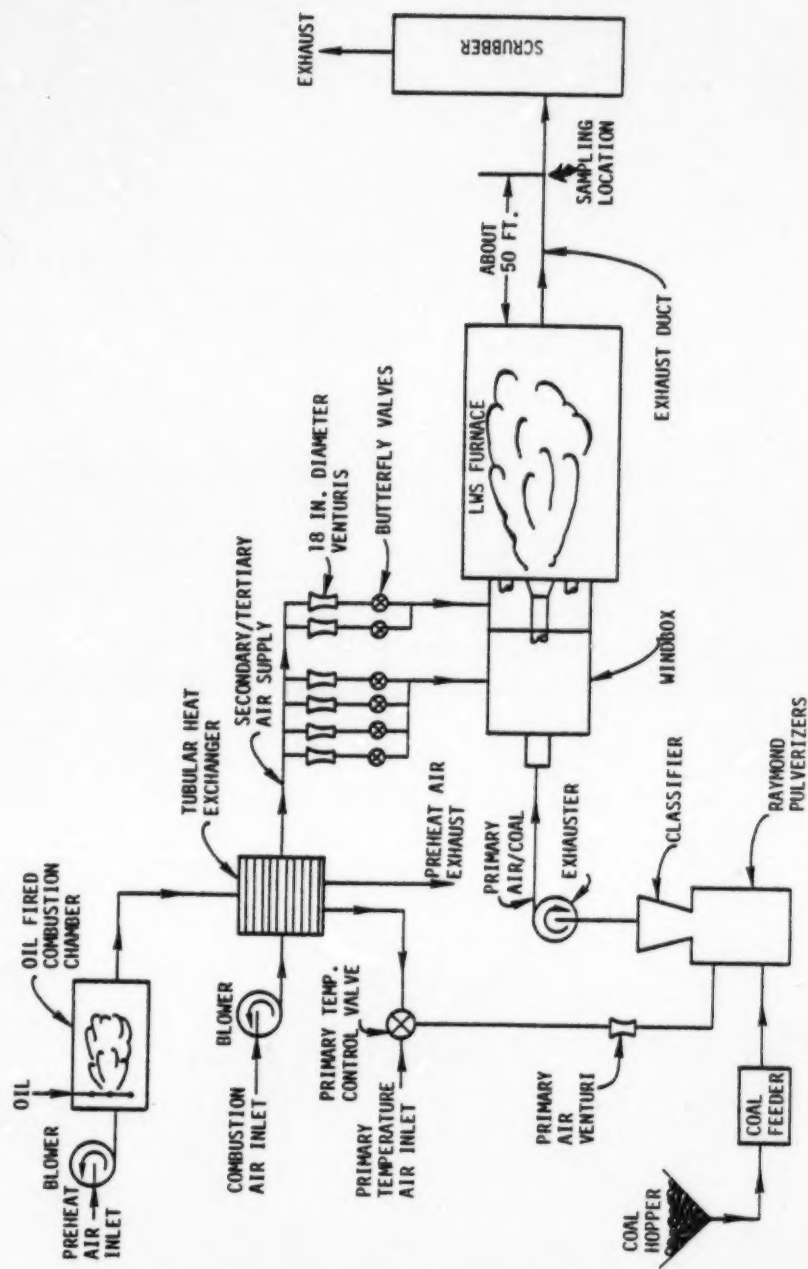


Figure A-1. Piping Diagram for Burner Tests.

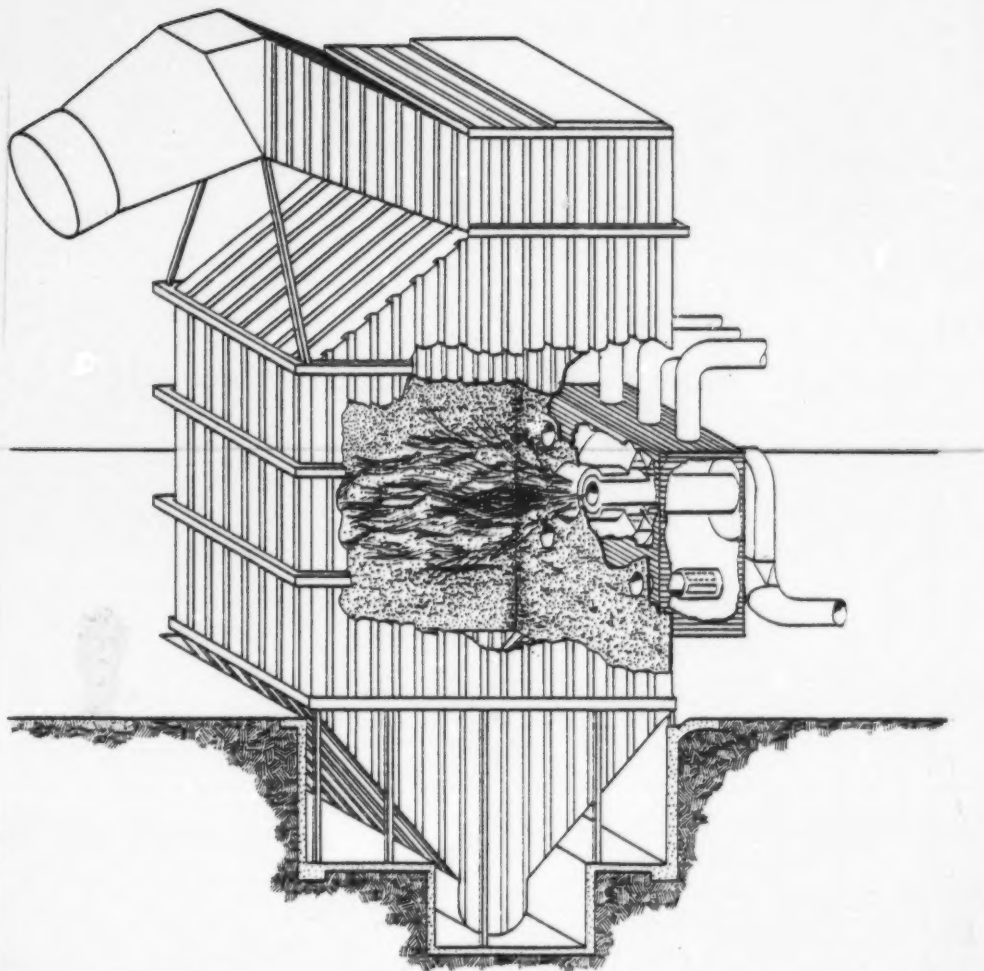


Figure A-2. LWS Furnace.

Table A-1. New LWS Furnace Characteristics

Parameter		Value
<u>Firing</u>		
Configuration	Primary	Single Wall
	Optional	Opposed or Corner
Firing Rate	Minimum	50×10^6 Btu/hr (Practical Limit)
	Maximum	150×10^6 Btu/hr
<u>Dimensions</u>		
Firing Depth		22 ft
Width		16 ft
Rear Wall Height		20 ft
Knuckle-to-Nose Heights		27.5 ft
Nose Angle		37° (from Horizontal)
Hopper Angle		52° (from Horizontal)
Height Above Ground Level		35.7 ft
Total Vertical Height		50.5 ft (Pit-to-Top)
<u>Cooled Surface Area</u>		
Burner Zone		704 ft^2
Total Furnace		1951 ft^2
<u>Volume</u>		
Burner Zone		3520 ft^3
Total Furnace		$11,544 \text{ ft}^3$ (to Nose)
<u>Insulation</u>		All Sidewalls Knuckle-up to 16 ft
<u>Cooling</u>		Spray-Cooled on All Surfaces

and the radiant surface area required for heat absorption. If these same criteria are applied to a single burner research furnace such as the LWS, the resulting furnace is a narrow tunnel. However, the fuel/air mixing characteristics and flame stability in a tunnel may be different than in a conventional rectangular furnace. The approach taken with the new LWS was to design a rectangular furnace with dimensions large enough to avoid flame impingement under most test conditions. This resulted in considerably larger volume and radiant surface area per unit of heat release than the demonstration boilers. To adjust the thermal characteristics, insulating refractory was applied to the vertical furnace walls.

Commercial burner manufacturers have found that the NO_x levels produced by their burners in boilers of their design can be approximately correlated with the total heat liberation per unit surface area in the furnace. Foster Wheeler's correlation uses a burner zone liberation rate (BZLR) defined as the net heat input to the burner burner zone divided by its effective projected surface. This surface is the area of the six-sided box starting at the hopper knuckle and extending 10 feet above the top row of burners and includes all cooled surfaces in that volume.

Babcock and Wilcox also have a correlation relating NO emissions (for their burners operating in boilers of their design) to heat release per unit surface area (HA/SC). However, the effective surface area is defined as the furnace plan area plus the areas of the vertical furnace walls from five feet below the lowest burner to five feet above the highest burner. For typical industrial and utility boilers, HA/SC is approximately 40 percent larger than BZLR.

Table A-2 compares several furnace thermal parameters for the LWS and the initial host boiler (WIPCO). The refractory insulation in the new LWS results in BZLR comparable to field conditions. However, the new LWS residence time and heat release per unit volume (Q/V) are somewhat different from the field values since they are primarily related to furnace geometry. Figure A-3 shows the relationships between BZLR and burner firing rates for the oil and new LWS, as well as the operating conditions for the two host boilers. The new LWS clearly more closely approximates field boiler operating conditions.

Table A-2. New LWS Operating Parameters

PARAMETER	BURNER FIRING RATE (10 ⁶ Btu/hr)			FIELD BOILER (WIPCO)	UNITS
	70	100	125		
Heat Release Per Unit Area (Total Furnace)	35.4	56.4	70.5	61.8	10 ³ Btu/hr/ft ²
Burner Zone Liberation Rate - BZLR	109.4	156.2	195.3	130.4	10 ³ Btu/hr/ft ²
Heat Release Per Unit Volume (Total Furnace)	6.0	8.6	10.7	17.1	10 ³ Btu/hr/ft ³
Residence Time (Total Furnace)	9.1	6.4	5.1	3.2	Sec
Residence Time (Burner Zone)	4.41	3.09	2.47	1.1	Sec
Furnace Exit Temperature	1600	1900	2050	1975	°F

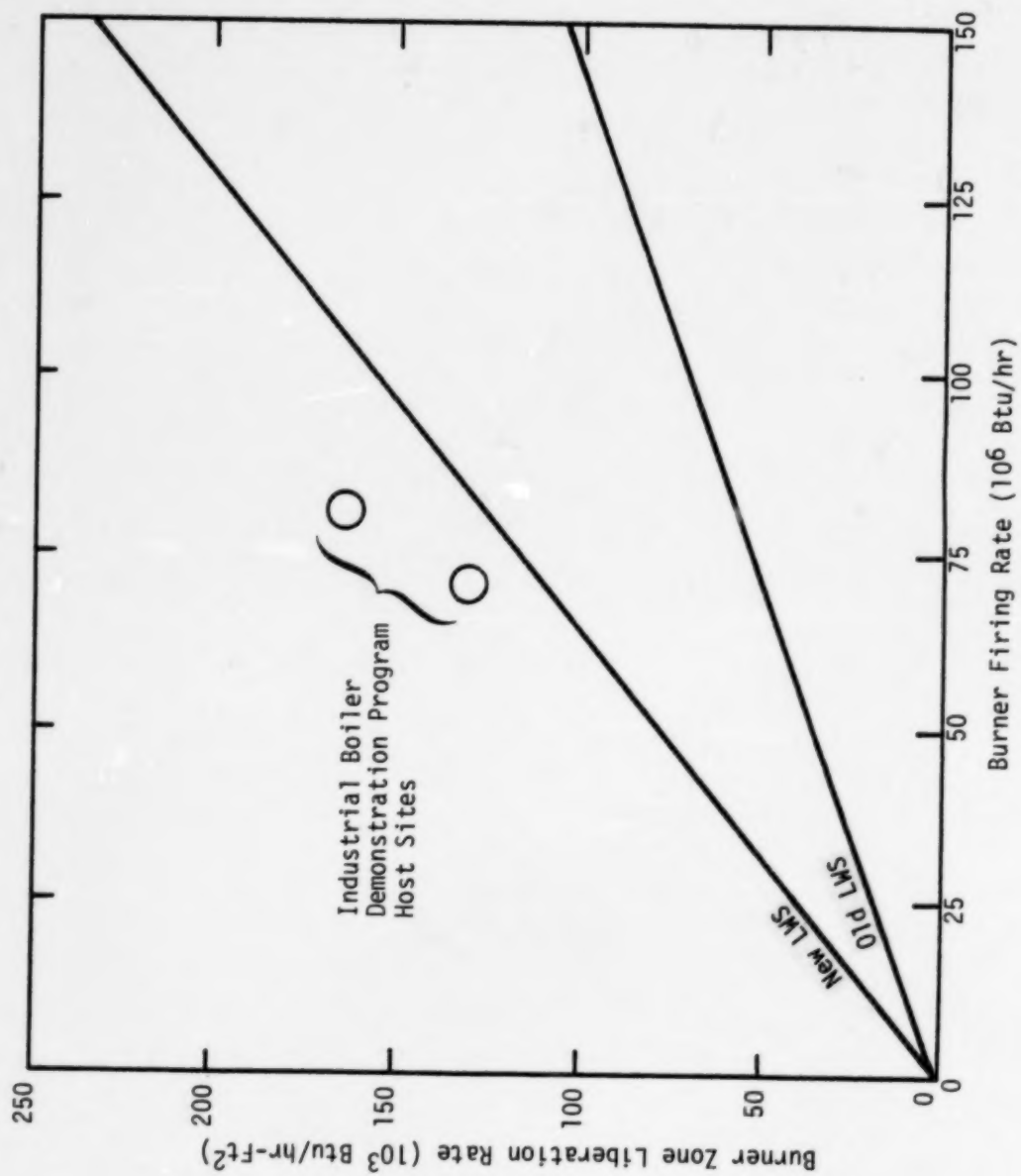


Figure A-3. Old and New LWS Thermal Characteristics.

Cooling

The entire external surface of the LWS is continuously sprayed with water to absorb the heat of combustion. The water is supplied at a rate several times that required for cooling so that all uninsulated surfaces remain in the range 250° to 300°F. Inside the furnace the flames are exposed to an average wall temperature comparable to field-operating boilers (i.e., a balance between uninsulated walls at about 300°F and insulated walls at up to 2400°F). Excess cooling water drains into a sump around the bottom of the hopper and is recycled through a cooling tower. The hopper walls are heavily sprayed with water to avoid buildup of molten ash particles and prevent operations similar to a wet bottom furnace.

Fuel Supply

Coal is stored in short piles adjacent to the test facility and is screened prior to entering the fuel feed system. A screw conveyer supplies a weight belt which meters the coal into the pulverizer. Two Raymond bowl-type pulverizers are available with nominal capacity of 80 and 150x10⁶ Btu/hr. Both have classifiers and exhausters. Primary air is supplied by the hot exhaust air from the combustion air preheater. Tempering air is blended as required to achieve the desired mill outlet temperature. Primary airflow rate is measured by a venturi.

Light distillate oil and/or residual oil are available for ignition or for oil-firing. Oil is supplied from an underground tank via a high pressure pump. The capacity is adequate to supply a 100x10⁶ Btu/hr burner. Steam and compressed air are available for atomization.

Air Supply

Nonvitiated combustion air is supplied by an indirect oil-fired heater and blower system. Combustion air temperatures from ambient to over 600°F can be achieved at the airflow rates required by burners up to 125x10⁶ Btu/hr. The airflow is measured with 18-inch venturis. Depending on the burner requirements, these venturis can be manifolded into a common windbox or connected directly to specific burner passages.

Exhaust

The combustion products exit the burner zone of the furnace and pass upward over the nose into the space normally occupied by superheater tubes in a steam generating boiler. They then enter a six-foot diameter spray-cooled exhaust duct which connects to a particulate/SO₂ scrubber. The sampling location is immediately upstream of the scrubber.

Old/New LWS Comparison

The differences in the old and new LWS furnace designs are expected to influence flame stability, CO emissions (and carbon burnout) and NO_x emissions. It is well known that flame stability is adversely affected by a cold furnace. In large multi-burner coal-fired furnaces it is necessary to preheat the furnace by oil-firing prior to the introduction of coal. Thus, the new LWS with a thermal environment similar to field operating boilers is expected to improve flame stability.

The final levels of CO and carbon in the fly ash depend on the thermal environment in the burner zone, as well as the temperature decay rate downstream of the burner zone. In the old LWS design, the furnace was cold and the exhaust was sampled at the furnace outlet (nose). This may have prematurely quenched the oxidation of carbon and CO as evidenced by the high CO levels measured on every burner tested including high turbulence pre-NSPS burners and DMB's. The new LWS, with its hotter furnace and sampling far downstream from the furnace are expected to result in lower CO and carbon in the flyash which will be more representative of field conditions.